Environ Resource Econ (2008) 39:45–54
DOI 10.1007/s10640-007-9174-8

The Incredible Economics of Geoengineering

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Accepted: 14 June 2007 / Published online: 6 December 2007

Abstract The focus of climate policy so far has been on reducing the accumulation of greenhouse gases. That approach, however, requires broad international cooperation and, being expensive, has been hindered by free riding; so far, little action has been taken. An alternative approach is to counteract climate change by reducing the amount of solar radiation that strikes the Earth—"geoengineering." In contrast to emission reductions, this approach is inexpensive and can be undertaken by a single country, unilaterally. But geoengineering also has worrying consequences: it may harm some countries; it would not address ocean acidification; it would pose new risks. The fundamental challenge posed by this new technology is not free riding but governance: who should decide if and under what circumstances geoengineering should be used?

Keywords Geoengineering · Climate change · Governance · Free riding

Geoengineering—which I shall take to be the deliberate modification of the climate by means other than by changing the atmospheric concentration of greenhouse gases—sounds like an idea conceived in Hollywood.[1] To most people, the suggestion seems crazy if not dangerous (Schelling 1996). For better or worse, however, it is a concept that needs to be taken seriously. As I shall explain in this paper, its future application seems more likely than not. This is partly because the incentives for countries to experiment with geoengineering, especially should

[1] Geoengineering is defined in various ways in the literature. To some, it includes planting trees to absorb CO_2. To others, it may involve carbon capture and storage, or enhanced take up of CO_2 by the oceans. For a comprehensive treatment, see Keith (2000). Here I focus deliberately on an option that differs fundamentally from "carbon management."

In my lecture to the British Association for the Advancement of Science, I gave an overview of my new book on global public goods (Barrett 2007), of which the topic of this paper is but one example. I have used the opportunity of this special issue to expand upon and recast my brief discussion of this topic as presented in my lecture and in the first chapter of this book

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climate change prove abrupt or catastrophic, are very strong. It is also because the incentives for countries to reduce their emissions are weaker. Geoengineering and emission reductions are substitutes.

Indeed, it is mainly because geoengineering and emission reductions are substitutes that the concept lacks "broad support from scientists" (Cicerone 2006: 221).[2] Not all scientists welcomed the recent publication of a paper by Paul Crutzen, a Nobel-prize-winning chemist, on geoengineering.[3] To acknowledge the feasibility of controlling the climate deliberately, these scientists fear, undercuts "human resolve to deal with the cause of the original problem, greenhouse gases in the case of climate change" (Cicerone 2006: 224). Crutzen understands this view; he only wrote about the subject reluctantly. He would prefer that emissions of greenhouse gases be cut to an extent that geoengineering would not be needed. He has only recognized the possible utility of geoengineering now because he despairs about the prospect of emissions being reduced enough, and quickly enough, to avoid dangerous climate change.

The suggestion here is that it would be better if countries could commit themselves not to resort to geoengineering. That way, the world would have no alternative but to reduce emissions.

There are, however, serious incentive problems associated with reducing emissions—problems that explain why so little has been done thus far, even with geoengineering being little discussed as a possible fallback. Indeed, even if emissions were reduced sharply and soon, we may prefer to keep the geoengineering option open because of the residual risk of abrupt climate change.

Moreover, it may be impossible for countries to keep a commitment to abstain from experimenting with geoengineering. The incentives for countries to reduce emissions on a substantial scale are too weak, and the incentives for them to develop geoengineering are too strong, for commitment to be a realistic prospect. Indeed, these two incentives combined are so powerful that many countries may be prepared to develop and deploy geoengineering unilaterally. That, I believe, is the greater danger.

Finally, and following on these two observations, a new governance arrangement is needed that places climate change policy in a broader context, recognizing that the objective should be to reduce climate change risk and that this requires a combination of efforts—on reducing emissions, certainly; but also on R&D into new energy technologies, on adaptation assistance to the poorest countries, and, yes, on geoengineering. This new framework should determine the circumstances under which geoengineering is to be permitted and proscribed.

1 A Brief Overview of Geoengineering

Two fundamental forces determine the Earth's climate: the amount of solar radiation that strikes the Earth and the amount of this radiation trapped by the atmosphere. The latter effect is determined by the concentration of greenhouse gases. The former depends on the solar cycle and the Milankovitch cycles that determine, over very long periods of time, how solar radiation is distributed.

[2] Economists have been perhaps a little more willing to discuss the concept; several distinguished economists, for example, participated in the Panel on Policy Implications of Greenhouse Warming (1992). Most economic analyses of climate change, however, have ignored geoengineering. I did not refer to it in my earlier book (Barrett 2005). It is not mentioned in *The Stern Review* (Stern 2007).

[3] In the same issue of *Climatic Change*, Ralph Cicerone, the president of the National Academy of Sciences, wrote, "I am aware that various individuals opposed the publication of Crutzen's paper, even after peer review and revisions, for various and sincere reasons that are not wholly scientific" (Cicerone 2006: 221).

Policy can shape these two forces by means of greenhouse gas and solar radiation management.[4] There does not exist a widely accepted definition of geoengineering, but as noted in the introduction I shall take it to mean deliberate climate modification by solar radiation management. This essentially means deflecting sunlight.

This already happens naturally. The eruption of Mount Pinatubo in the Philippines in 1991 injected huge quantities of sulfur dioxide into the stratosphere, lowering the Earth's surface temperature by about 0.5°C the year following the eruption (Crutzen 2006). Human activities are also causing backscattering now—unwittingly. When coal is burned, sulfate particles are thrown into the troposphere, increasing albedo.[5] These particles, however, are harmful to human health and ecosystems; they should be, and increasingly are being, reduced. Indeed, it is partly for this reason that solar radiation has increased. Reducing concentrations of sulfate particles exacerbates "global warming."

The sulfate particles we put into the atmosphere are inefficient deflectors. Particles injected higher up into the stratosphere linger for longer—years rather than weeks. Engineered particles are expected to perform better still, reducing the total mass of material that would have to be injected to achieve a given cooling effect.

Geoengineering is a stopgap measure, a "quick fix," a "Band-Aid." It is akin to adding ground limestone to Sweden's pH-sensitive lakes and soils. Though only reductions in acidic emissions can prevent acid rain, liming preserves pH balance; it prevents acid rain damage. Geoengineering would have a similar effect. It would not address the underlying cause of climate change, but if it worked as intended it would prevent temperatures from rising against a background of elevated atmospheric concentrations of greenhouse gases.[6]

Its main advantage might be in stemming abrupt and catastrophic climate change. Abrupt climate change would take place over a period of perhaps a decade or two—too short a period for emission reductions to be able to stop it. By contrast, the climate response of albedo enhancement would take hold in a matter of months (Crutzen 2006). Catastrophic climate change would likely unfold over a number of centuries, but avoiding it will require a technological revolution, and geoengineering might help to "buy time" to develop and diffuse these new technologies (Wigley 2006).

Here is another way to look at this: It has been widely suggested that global mean temperature should not be allowed to increase by more than 2°C. At a concentration level of 550 parts per million CO_2, mean global temperature is likely to rise 1.5–4.5°C.[7] Put differently, to be confident (but not certain) of limiting temperature change to 2°C, concentrations would have to be capped at a level far below 550 ppm—to a level more like 380 ppm (Caldiera et al. 2003: 2052). That would mean capping concentrations at the current level, and without a mass adoption of "air capture," this goal is essentially unattainable. Geoengineering might therefore be an indispensable ingredient of a policy aiming to ensure that mean global temperature rises by no more than 2°C.

Would geoengineering work? As mentioned previously, the effect of volcanoes and sulfate pollution has been measured; we know that these natural and inadvertent interventions work. So far, the efficacy of deliberate climate engineering has been demonstrated only in computer models. Wigley (2006: 452) reasons that, since the Mount Pinatubo eruption did not

[4] Climate change is also determined by land surface properties, and policy could seek to change the Earth's surface albedo. However, this approach is also problematic and less efficient than atmospheric scattering; see MacCracken (2006).

[5] The condensation trails left by jet aircraft may have a similar effect; see Travis et al. (2002).

[6] For a more general discussion of quick fixes, see Sterner et al. (2006).

[7] According to the latest IPCC assessment (IPCC 2007: 9), climate sensitivity is "*likely* to be in the range of 2–4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C."

"seriously disrupt the climate system," deliberately adding the same loading should "present minimal climate risks." Simulating the effects of adding a Mount Pinatubo eruption every year, every two years, and every four years, he finds that the biennial eruption "would be sufficient to offset much of the anthropogenic warming expected over the next century."

Though global mean temperature can be controlled by changing solar reflectivity as well as by limiting greenhouse gas concentrations, the physics of these approaches differ. They may have different effects on the geographic distribution of temperatures. Computer simulations by Govindasamy and Caldeira (2000) and Govindasamy et al. (2003), however, have shown that geoengineering would likely have little effect on the spatial pattern of surface temperatures. The distribution of temperature seems to be determined by more fundamental forces.

Geoengineering would affect more than the climate; it would have other environmental effects. Stratospheric aerosols could destroy ozone, as did the aerosols released by Mount Pinatubo. However, this damage is expected to be modest (Robock 2002). According to Paul Crutzen (2006: 215), a co-recipient of the 1995 Nobel Prize in chemistry for research on the ozone layer, the geoengineering needed to compensate for a doubling in carbon dioxide concentrations "would lead to larger ozone loss but not as large as after Mount Pinatubo"—and this against a background of expected rising ozone levels overall because of the success of the Montreal Protocol. As well, the risks from geoengineering would be bounded; aerosols pumped into the stratosphere would survive only a few years, much less than greenhouse gases (some of which can persist for more than a millennium). Geoengineering may even offer environmental benefits, the main one being the blocking of harmful UV radiation by engineered particles (Teller et al. 2003). Here again, however, there would be a trade off, as it is likely that such particles would also extend the atmospheric life of other greenhouse gases, reducing the overall cooling effect.

Particles thrown into the stratosphere would be transported towards the poles (their residency would thus be maximized if released over the equator) where they would "rain out." The effects may not be significant, however, since the amounts that would be added are a small fraction of the current input by pollution and volcanic eruptions (Crutzen 2006: 213).

Like volcanic eruptions, geoengineering would change the color of the sky. Volcanic particles whiten the sky by day (an environmental loss, presumably, though one that is already being caused by atmospheric pollution), but make sunsets and sunrises more vibrant (Crutzen 2006).

Some of the consequences of geoengineering may surprise us. Geoengineering would constitute a large-scale experiment (though that is also true of the experiment geoengineering is meant to correct, that of rising concentrations of greenhouse gases). Computer simulations offer a hint as to the likely consequences, but they can provide no more than this. The geoengineering experiment could be undertaken on a limited scale—a small volume of aerosols might be added initially, and released over the higher latitudes. Very importantly, the experiment could be halted, should adverse effects appear. Barring irreversibilities, the effects of geoengineering—positive and negative—would only be transitory.

Still, geoengineering amounts to putting something into the environment that wasn't previously there; reducing emissions, by contrast, amounts to not adding something that wasn't there. Of the two approaches, mitigation is the more conservative option—the reason it is preferred by scientists. However, the risks are not so one-sided. Mitigation cannot be relied upon to be benign. To reduce emissions substantially and in the near term will require an expansion in nuclear power, creating problems for safety, waste storage, and proliferation (Ansolabehere et al. 2003). Carbon capture and storage holds the promise of allowing countries to burn coal without releasing greenhouse gases into the atmosphere, but sinking carbon into the oceans would also amount to adding something to the environment that wasn't previously there; it would therefore also entail environmental risk (Anderson and Newell 2004).

One effect of geoengineering is unambiguous: it would do nothing to address the related problem of ocean acidification. The oceans absorb a portion of the carbon dioxide pumped into the atmosphere. This decreases the pH level of the oceans and is likely to change the process of calcification, endangering animals such as corals (which may, however, be bleached by rising ocean temperatures long before geoengineering is ever tried) and clams. Limestone could be added to the oceans, just as we have added limestone to acid-sensitive lakes, but liming is likely to be feasible only for certain sensitive areas (Royal Society 2005). It is not a comprehensive answer to the problem.

2 Geoengineering Economics

The economics of geoengineering are—there is no better word for it—incredible. Upon reviewing the options in depth, the Panel on Policy Implications of Greenhouse Warming (1992: 460) concluded by saying that, "one of the surprises of this analysis is the relatively low costs at which some of the geoengineering options might be implemented." The Panel (1992: 452, 454) calculated that adding stratospheric aerosol dust to the stratosphere would cost just pennies per ton of CO_2 mitigated. Drawing on this study, Nordhaus (1994: 81) concluded that offsetting all greenhouse gas emissions today would cost about \$8 billion per year—an amount so low that he treats the geoengineering option as being costless. According to Teller et al. (2003: 5), engineered particles would be even cheaper (mainly because of the reduced volume of material that would need to be put into the stratosphere); they estimate that the sunlight scattering needed to offset the warming effect of rising greenhouse gas concentrations by the year 2100 would cost just \$1 billion per year. Keith (2000: 263) thinks this is an optimistic estimate, but says that, "it is unlikely that cost would play any significant role in a decision to deploy stratospheric scatterers because the cost of any such system is trivial compared to the cost of other mitigation options."

Taking into account the effect of engineered particles on scattering harmful UV radiation, Teller and his colleagues calculate that this health-related benefit for the U.S. alone would exceed the total cost of geoengineering by more than an order of magnitude (Teller et al. 2003: 5–6). If correct, the economics are even more favorable than suggested above. Deliberate climate modification would also allow carbon dioxide concentrations to remain elevated—an aid to agriculture.[8]

Just as important as the cost of geoengineering relative to emission reductions is the nature of these two options. Geoengineering constitutes a large project (Schelling 1996). By means of this technology, a single country, acting alone, can offset its own emissions—and those of every other country. By contrast, mitigating climate change by reducing emissions requires unprecedented international cooperation and very substantial costs. Stabilizing atmospheric concentrations requires a 60–80% cut in CO_2 emissions worldwide. In the years since the Framework Convention on Climate Change was adopted, global emissions have risen about 20%. Even if the Kyoto Protocol is implemented to the letter, global emissions will keep on

[8] Govindasamy et al. (2002) estimate that the global dimming needed to offset a doubling in CO_2 concentrations (a 1.8% reduction in solar flux) would reduce net primary productivity by about 3%, whereas the higher CO_2 would increase net primary productivity about 76%. Though beneficial for agriculture overall, these changes would also affect the balance of sensitive ecosystems.

rising. So will concentrations. Theory points to the difficulty in achieving substantial and wide scale cooperation for this problem, and the record to date sadly supports this prediction.[9]

A quick calculation hints at the temptation presented by geoengineering. According to Nordhaus and Boyer (2000: 131), climate change might cost the United States alone about \$82 billion in present value terms. Using a three percent rate of discount, this is equivalent to an annual loss of about \$2.5 billion. If the U.S. cut its emissions, it could reduce this damage somewhat. If it turned to geoengineering, it could eliminate this damage. If geoengineering is as cheap and effective as is claimed, the U.S. might prefer the geoengineering option. So, of course, might other countries.

Denote the benefits to Country i by B_i and assign numerical labels to countries that reflect their relative benefits, such that $B_1 > B_2 > \cdots > B_N$. Finally, let the cost of geoengineering be denoted C. Then, so long as $B_1 > C$, we can be pretty sure that geoengineering will be tried (using it would be the Nash equilibrium). It may not be tried by Country 1. Any country j for which $B_j > C$ would be willing to try it, should all others not try it. Countries might even agree to pool their resources, to share the costs. We cannot predict which country or group of countries will bear the cost, but it is clear that the incentive for geoengineering to be tried is very strong so long as the costs are low. Even if the costs turn out to be much higher (such that $C > B_1$), and no country has an incentive to try geoengineering unilaterally, a coalition of k countries would have an incentive to do so collectively so long as $B_1 + \cdots + B_k > C$ (In this case, using geoengineering would be a Nash equilibrium but so would not using geoengineering).

Climatologist Michael MacCracken (2006: 238) argues that, “Although it might be conceivable for one nation to actually commit to such a program, it seems rather unlikely that a global coalition of nations could be kept together to sustain such a diversion of resources for a task that would seem, to the typical citizen, to generate no immediate or direct benefits.” I disagree. There is no need for countries to commit to sustaining a geoengineering intervention. It is true that there are a huge number of Nash equilibria to the cost-sharing game. But were a geoengineering effort to be shut off, the climate would respond very rapidly (Wigley 2006). Any country that had an incentive to join a coalition of countries in financing a geoengineering project initially would have at least as strong an incentive to continue with it later—unless, of course, in the meantime, previous efforts at reducing emissions succeeded in lowering atmospheric concentrations.

This last possibility is the scenario examined by Wigley (2006). He considers the role that geoengineering might play in “buying time” for a policy needed to stabilize concentrations. To be more specific, he shows how geoengineering could be used to smooth the hump caused by overshooting a concentrations target. This may be an attractive use of geoengineering, but in this case there is a commitment problem. If geoengineering should prove benign, the incentive to reduce atmospheric concentrations would be muted. A promise to use geoengineering only temporarily may thus lack credibility.

3 Geoengineering Governance

Ironically, the attributes that make geoengineering attractive also make it worrying. Because it consists of a single project, it can be undertaken unilaterally or minilaterally. Because of its low cost, the incentives for it to be tried are very strong. The consequences of one country

[9] On the theory of cooperation in this area, see Barrett (2005). In Barrett (2006a) I consider what I believe to be a particularly promising approach. However, even here the prognosis is discouraging. It was only after writing this paper that I began to consider seriously the possibility of geoengineering.

or a small number of countries using it, however, would be global; and they might not all be welcome (Schneider 2001).

So, who is to decide whether geoengineering should be deployed? Should a country be allowed to do so unilaterally? Could it be prevented from doing so? Some countries are expected to benefit from climate change, at least gradual climate change through this century. According to Nordhaus and Boyer (2000: 131), for example, Russia, China, and Canada would all gain. Would these countries need to be compensated for damages resulting from a geoengineering intervention to limit climate change? If the losers from climate change use geoengineering to cool temperatures, might the winners use geoengineering to *absorb*, rather than to scatter, radiation? (Might there be geoengineering wars?) Could *they* be prevented from doing so? Would countries be allowed to engineer any temperature, or would they only be permitted to limit change from the recent historical average? The world's poorest countries are especially vulnerable to climate change, and yet they are likely to be the least able to develop and deploy a geoengineering effort. Should the more capable states be required to do so for them?[10] Should they be made to pay compensation if they do not? Suppose geoengineering affected the spatial distribution of climate, even if it succeeded in preventing the global (average) climate from changing. Should the countries adversely affected be compensated? How would damages be determined? Which countries would be expected to pay compensation? How could the obligation to pay be enforced? What about countries that have different attitudes towards risk, or that object to the idea of deliberately altering the climate whatever the benefits may be? Should their views be heeded?

Two precedents offer a glimpse into how these concerns might be addressed. The first concerns experiments with a different kind of particle. The Large Hadron Collider being built in Europe is intended to test the Standard Model of particle physics. The knowledge gained from this project will be a global public good, but there is a small chance that the experiment could create something called a strangelet—an object that, by a process of contagion, might possibly "transform the entire planet Earth into an inert hyperdense sphere about 100 m across" (Rees 2003: 121). It is even conceivable that the particle smashes might create a growing black hole—a phenomenon that might destroy not just the Earth but the entire universe. A report written for the backers of the Large Hadron Collider concludes that there is "no basis for any conceivable threat" (Blaizot et al. 2003: iii). But the likelihood of a strangelet being created is impossible to calculate with certainty, since the experiment has never taken place before. Existing theories are reassuring, but they have not been tested. And do we really want to test them? Are we sure that the global public good of new knowledge outweighs the global public bad of the risk of annihilation?

More importantly, who should decide whether the experiments should go ahead? So far, the decision has been left to the parties that are financing the project—the 20 European members states of CERN (officially, the European Organization for Nuclear Research), the organization that is building and that will run the Large Hadron Collider, and its partners on this project—India, Japan, Russia, and the United States.[11] But should other countries have been consulted? Should other countries have a veto?

[10] There is a similarity here with the new norm of "the responsibility to protect," which requires that the major powers intervene to stop genocide. As the current situation in Darfur shows, the problem here is that the major powers are declining to act; they are declining to fulfill their responsibility. See the concluding chapter of Barrett (2007).

[11] The members of CERN include Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Norway, the Netherlands, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, and the United Kingdom.

The second precedent concerns the remaining stocks of smallpox virus. Smallpox was eradicated in 1977, yielding every country a huge dividend (Barrett 2006b). Provision of this global public good meant that people no longer needed to die of this disease. It meant also that there was no longer a need for people to be vaccinated. Unfortunately, reaping this dividend has exposed countries to a new risk. If smallpox were somehow reintroduced today, the world would be more vulnerable than ever to an epidemic. So long as smallpox exists, this risk remains. Concern about a possible accidental release caused laboratories around the world to destroy or transfer their stocks; by 1983, known stockpiles of smallpox virus were held by just two World Health Organization (WHO) "collaborating centers," one in Atlanta and the other in Moscow. But were these the *only* remaining stocks left? Unfortunately, no one could be sure. Some people suspected that covert stocks might have been retained by other states. That concern persists today.

What to do with the last two known stockpiles? In 1986 and again in 1990, the WHO's Committee on Orthopoxvirus Infections recommended that the stocks held in Atlanta and Moscow should be destroyed. But while destruction would eliminate the risk of an accidental release, it would also foreclose the option of using the remaining stocks to develop improved diagnostic tools, antiviral drugs, and a novel vaccine—innovations that would benefit the whole world should covert stocks exist and should smallpox virus be released deliberately some day. As with geoengineering, the decision to destroy the remaining stores of smallpox entails a risk-risk tradeoff. It also has implications for every country.

Again the question: Who should decide? The two states that possess the virus obviously have the upper hand (just as the major powers would have the upper hand in developing a geoengineering project), but being WHO collaborating centers, the labs in Atlanta and Moscow are obligated to serve the global interest.

In 1998, the WHO polled its 190 members. Did they want the last known stocks to be retained or destroyed? The survey revealed a split. Russia wanted to hold onto its samples; Britain, France, Italy, and the United States were undecided; every other country (74 other countries responded) favored destruction. Concerned about the risk of a bioterrorist attack, the United States changed its position in 1999, asserting a need to keep its stockpile. When the World Health Assembly met shortly after this, a compromise was worked out. A resolution was proposed that reaffirmed the goal of *eventual* destruction but permitted Russia and the U.S. to retain their stocks for research purposes for a period of three years. The resolution passed by acclamation. Later the reprieve was extended; and, today, smallpox virus is still kept at the two WHO centers. Inspectors have satisfied the WHO's Advisory Committee on Variola Virus Research that the stocks are secure, and the Committee has verified that the research undertaken at both labs has progressed. They have also confirmed, however, that the job is not yet finished. Their judgment is that there is still reason to retain smallpox for research purposes.

The arrangements surrounding the decision to retain the smallpox stocks are very different from those connected with the conduct of possibly dangerous experiments. The latter are being undertaken by a relatively small number of countries, without wider consultation let alone approval. The smallpox decision, by contrast, has been undertaken in a setting in which all the world's countries were invited to take part. To be sure, in this case the power relations among countries are vastly unequal. But the process that emerged favored consensus—an especially fortunate outcome. Since every country will be affected by whatever is decided, it is as well that each should agree with the decision.

As matters now stand, the situation with geoengineering is more akin to the regime for carrying out particle collider experiments than to the smallpox decision. Currently, there is no institutional arrangement that says what countries are allowed to do or not to do as regards geoengineering. By default, therefore, countries are pretty much free to explore geoengineering options or not as they please. It may be unlikely that countries would seek to act unilaterally (Bodansky 1996), or as part of a "coalition of the willing," but that possibility will remain unless and until climate engineering is brought into an institutional framework of some kind.

How to proceed? Three steps are needed. First, the possibility of geoengineering should be examined in detail by the Intergovernmental Panel on Climate Change (2007), in a special report. Its pros and cons need to be evaluated, and all countries need to be made aware of them. Second, and drawing on this technical work, the Framework Convention on Climate Change should be revised. This agreement has the great advantage of having nearly universal participation (the only non-parties are Andorra, Brunei, the Holy See, Iraq, and Somalia, and these states are free to join when their circumstances permit). Currently, however, the Framework Convention embraces the objective of stabilizing atmospheric concentrations of greenhouse gases; it does not mention geoengineering. A revised convention should emphasize the need to reduce climate change risk—a broader objective that would encompass not only efforts to reduce atmospheric concentrations but also adaptation (which is mentioned in the Convention), R&D into new energy technologies, and geoengineering. Finally, and building upon the first two steps, a new protocol should be added that specifies whether and under what conditions geoengineering should be allowed (even if only for research purposes), or possibly even required, and how the costs of any efforts should be shared.[12]

4 Conclusion

Mitigating, forestalling, or averting global climate change is a global public good. Supplying it by means of reducing emissions is vulnerable to free riding. Too few countries are likely to participate in such an effort, those that do participate are likely to reduce their emissions by too little, and even their efforts may be overwhelmed by trade leakage (Barrett 2005). Geoengineering presents a very different set of incentives. A single country can deploy a geoengineering project on its own—and the economics of geoengineering are so attractive that it seems likely that a country, or perhaps a small group of countries, may want to try to do so at some point in the future, especially should the worst fears about climate change ever unfold.

The challenge posed by geoengineering is not how to get countries to do it. It is to address the fundamental question of who should decide whether and how geoengineering should be attempted—a problem of governance (Barrett 2007). Failure to acknowledge the possibility of geoengineering may or may not spur countries to reduce their emissions, but it will mean that countries will be unrestrained should the day come when they would want to experiment with this technology.[13] This, to my mind, is the greater danger.

[12] Cost sharing has the advantage of widening decision making to include a greater number of countries; see Barrett (2007), Chap. 4. The conditions noted here could include a moratorium, as suggested by Cicerone (2006).

[13] A secondary problem is that the countries capable of using geoengineering may not use it to help countries in need but lacking such a capability. This is allied to the problem of the rich countries providing adaptation assistance to the poor, and another reason why all the policy dimensions of climate change need to be evaluated jointly.

References

Anderson S, Newell R (2004) Prospects for carbon capture and storage technologies. Annu Rev Environ Resour 29:109–142

Ansolabehere S, Deutch J, Driscoll M, Gray PE, Holdren JP, Joskow PL, Lester RK, Moniz EJ, Dodreas NE (2003) The future of nuclear power: an interdisciplinary MIT study. Massachusetts Institute of Technology, Cambridge, MA

Barrett S (2005) Environment and statecraft: the strategy of environmental treaty-making (paperback edition). Oxford University Press, Oxford

Barrett S (2006a) Climate treaties and 'breakthrough' technologies. Am Econ Rev Pap Proc 96(2):22–25

Barrett S (2006b) The smallpox eradication game. Public Choice 130:179–207

Barrett S (2007) Why cooperate? The incentive to supply global public goods. Oxford University Press, Oxford

Blaizot J-P, Iliopoulos J, Madsen J, Ross GG, Sonderegger P, Specht H-J (2003) Study of potentially dangerous events during heavy-ion collisions at the LHC: report of the LHC safety study group. Geneva, CERN 2003-001

Bodansky D (1996) May we engineer the climate?. Clim Change 33:309–321

Caldeira K, Jain AK, Hoffert MI (2003) Climate sensitivity uncertainty and the need for energy without CO_2 emission. Science 299:2052–2054

Cicerone RJ (2006) Geoengineering: encouraging research and overseeing implementation. Clim Change 77:221–226

Crutzen PJ (2006) Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?. Clim Change 77:211–219

Govindasamy B, Caldeira K (2000) Geoengineering earth's radiation balance to mitigate CO_2-induced climate change. Geophys Res Lett 27(14):2141–2144

Govindasamy B, Caldeira K, Duffy PB (2003) Geoengineering earth's radiation balance to mitigate climate change from a quadrupling of CO_2. Glob Planet Change 37:157–168

Govindasamy B, Thompson S, Duffy PB, Caldeira K, Delire C (2002) Impact of geoengineering schemes on the terrestrial biosphere. Geophys Res Lett 29(22):2061 doi.1029/2002GL015911

Intergovernmental Panel on Climate Change (2007) Climate change 2007: the physical science basis. Summary for policymakers. Available at http://www.ipcc.ch/SPM2feb07.pdf

Keith DW (2000) Geoengineering the climate: history and prospect. Annu Rev Energy Environ 25:245–284

MacCracken MC (2006) Geoengineering: worthy of cautious evaluation?. Clim Change 77:235–243

Nordhaus WD (1994) Managing the global commons: the economics of climate change. MIT Press, Cambridge, MA

Nordhaus WD, Boyer J (2000) Warming the world: economic models of global warming. MIT Press, Cambridge, MA

Panel on Policy Implications of Greenhouse Warming (1992) Policy implications of greenhouse warming: mitigation, adaptation, and the science base. National Academy Press, Washington, DC

Rees M (2003) Our final hour. Basic Books, New York

Robock A (2002) The climatic aftermath. Science 295:1242–1243

Royal Society (2005) Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society, London

Schelling TC (1996) The economic diplomacy of geoengineering. Clim Change 33:303–307

Schneider SH (2001) Earth systems engineering and management. Nature 409:417–421

Stern N (2007) The economics of climate change: the Stern review. Cambridge University Press, Cambridge

Sterner T, Troell M, Aniyar S, Barrett S, Brock W, Carpenter S, Chopra K, Ehrlich P, Hoel M, Levin S, Mäler K-G, Norberg J, Pihl L, Söderqvist T, Wilen J, Vincent J, Xepapadeas A (2006) Natural disasters and disastrous policies. Environment 48(10):20–27

Teller E, Hyde R, Ishikawa M, Nuckolls J, Wood L (2003) Active stabilization of climate: inexpensive, low risk, near-term options for preventing global warming and ice ages via technologically varied solar radiative forcing. Lawrence Livermore National Library, 30 November

Travis DJ, Carleton AM, Lauritsen RG (2002) Contrails reduce daily temperature range. Nature 418:601

Wigley TML (2006) A combined mitigation/geoengineering approach to climate stabilization. Science 314:452–454