conclusively addressed at the international level. Instead, the final decision to authorize a geoengineering experiment will remain to be taken by the responsible national authorities, even though on the basis of the specifically applicable international. The situation would be different only if one or more geoengineering technologies were specifically prohibited or allowed at the international level. There are no indications that this will occur in the near future, however. Amendments to the London Protocol to regulate ocean fertilization that are presently discussed[44] would, in case of their adoption by the State parties, adhere to the fact that decisions on the admissibility of geoengineering experiments will have to be taken on the national level by the competent authorities of the State in accordance with general international law and the individual framework set by the London Protocol. As such, they would constitute a specifically applicable occurrence of the risk-balancing scheme discussed above and, indeed, a mechanism for adapting the general content and nature of the precautionary principle to a particular geoengineering technology.

44 Cf. LP CO_2 5/1/1 of 31 March 2012.

4. Conclusion

Because scientific uncertainty in regard to both the potential negative impacts of geoengineering on the environment and the adverse consequences of climate change is unlikely to be resolved in the near future, regulatory strategies are called for which enable a flexible approach to new scientific findings and developments. This cannot be achieved by establishing norms of obligation or prohibition – a proposition which is already unrealistic due to the divergence of interests in the international community. If one accepts that it will be necessary in the future to answer the question on a case-by-case basis as to which potential environmental impacts are acceptable from geoengineering methods that are potentially suitable for mitigating the adverse effects of global warming, particular attention should be paid to the procedural safeguarding of decisions made on the basis of risk assessments. In addition, the general customary duties to conduct consultations and perform EIAs in the context of the pertinent treaties ought to be adapted to the specifics of the geoengineering methods in question and effectively implemented at the international level.

What are the Costs and Benefits of Climate Engineering? And Can We Assess Them?

Gernot Klepper*

Abstract: Climate engineering is discussed as an alternative to the control of greenhouse gas emissions because it is perceived that there will be no sufficiently strong international agreement on effective climate policy measures and that many climate engineering technologies can be implemented at very low cost compared to emission control. We argue that the costs and benefits of climate engineering are so far essentially unknown and in many cases no adequate concept of the costs is used. Economic cost concepts are likely to show that the cost of climate engineering will be larger than currently perceived. However, many costs will be very difficult to quantify, thus making a full cost-benefit analysis essentially impossible and requiring a debate that goes beyond purely economic arguments.

Keywords: Climate engineering, economic cost, unintended side-effects
Klima-Engineering, wirtschaftliche Kosten, nichtintendierte Nebeneffekte

1. Introduction

Climate Engineering (CE) is the large-scale manipulation of the earth's radiation balance in order to counteract the fundamental changes of the earth system brought about by the continued emissions of greenhouse gas (GHG). Although the desire of the international community to limit the average temperature increase to 2°C within this century has been repeatedly confirmed – once again at the recent meeting of the parties to the United Nations Framework Convention (UNFCCC) in Durban, this desire has not been supported by agreements to control the increase in GHG and eventually reduce them to very low levels. It is therefore not surprising that an increasing interest in CE can be observed. First small-scale field test of CE technologies are currently planned in the United States with privately funded money (e.g., in New Mexico).[1] At the same time strong opposition starts to form in several areas of civil society (e.g., ETC or Hand off Mother Earth Campaign).

Manipulating the weather is a century-old idea, although it was never clear whether the attempts have been successful. Nevertheless, the idea has also been transferred from weather

* Prof. Gernot Klepper Ph.D., Head of Research Area "The Environment and Natural Resources" at the Kiel Institute for the World Economy, Kiel, Germany
1 guardian.co.uk, Tuesday 17 July 2012 13.21 BST

to climate events. Already in the 1960s first ideas to engineer the climate to mitigate climate change were discussed. The seminal paper of Paul Crutzen in 2006 brought these ideas back into the discussion, in particular as an emergency option if conventional emission control will not appear to be sufficient to “avoid dangerous climate change” as agreed upon in Art. 2 of the UNFCCC.

2. The Origins of CE and the Economic Arguments in Favor of it

CE is an idea propagated by engineers and has significant military aspects.[2] Yet, the idea to use it as an instrument to counteract climate change, especially global warming, brought economists to the debate. Schelling (1996) and Barrett (2009) emphasized the opportunity that the global problem of climate change could be addressed with measures that could easily be implemented by a single country or small group of countries. In 2008 Scott Barrett[3] wrote a paper on “The incredible economics of geoengineering”, in which he argued that the potentially low cost of CE measures together with the quick response of the earth’s temperature to such interventions will change the whole debate about the mitigation of climate change. His most important argument was related to “Radiation Management (RM)”.[4] RM measures, he argues, have such low cost that it would be very hard to argue against their use as substitute for measures to reduce the emissions of GHGs. Barrett’s argument has become conventional wisdom in many debates and has driven many activities in research.

Several critical assumptions are connected to Barrett’s statement. First of all, the question is: How should costs of RM measures be defined? Secondly, how should their benefits be defined, measured, and verified? And since we are talking about very complex issues with very little information, the third question is: How should a cost-benefit comparison deal with the inherent uncertainties in assessing both costs and benefits? I will deal with these questions both for RM and CDR measures in the following.

3. The Costs of CE

There are substantial differences but also several similarities when one attempts to define the cost of CE measures as to whether one considers Carbon Dioxide Removal (CDR) or Radiation Management (RM). In order to highlight them it is helpful to discuss the different notions of the cost of CE measures. One can essentially distinguish three dimensions of costs. The narrowest definition refers to the operating costs of a particular CE activity. The operating costs encompass the running costs of performing a CE activity. E.g., the operating costs of carbon capture include the capital, labor, and material costs of running the installation for capturing CO_2 from the atmosphere, for transporting and for sequestering the CO_2 in a permanent storage. For RM measures this would be very similar. Aerosol injection has operating costs for bringing the aerosols in the desired height of the atmosphere. For the cost computation current prices are used.

The assumption of constant prices can be disputed for several CE measures. Since CE attempts to influence either the CO_2 concentration or the radiation balance on a global scale, some of these measures require large quantities of inputs. This additional demand may in some cases lead to price increases in markets for material inputs or capital goods. These market price effects may result in an underestimation of operating costs if they are computed with constant prices.

The third dimension of the cost of CE measures relates to their impact. For example, a RM measure is intended to reduce the temperature of the earth. However, it also changes several other cycles of the earth system such as precipitation patterns. These unintended side effects can lead to substantial economic costs for some world regions, although there are so far no detailed model simulations on the economic costs of such effects. These external effects need to be added to the operating costs. At the same time, a RM measure may in some regions also have positive unintended side effects that should reduce the costs of the RM measure. Conventional cost-benefit analyses would simply count the net effect of these regional side effects. However, it is at least questionable as to whether such an adding up of costs and benefits across world regions and across very different income levels is appropriate.

There are two dimensions which make this adding up questionable. The first concerns the distributional effects. A particular CE activity may result in the desired temperature reduction or carbon removal at low operating costs, but it may be accompanied by large side effects for some states. These external costs may be negligible on a global scale. However, if the countries negatively affected are not compensated for their costs, the CE activity may raise concerns of distributional justice. In addition, it may lead to international political repercussions if the CE activity has been introduced unilaterally or by a small group of states.

The other concern about simply adding up costs is related to international law. According to customary international law, states have to take due regard of territorial integrity of other states. Especially for RM measures this principle may be violated since the intent of RM measures is exactly to create an effect that cuts across national boundaries by lowering the global temperature. In other words, as long as a CE activity is not introduced by a global consensus, a cost-benefit argument in favor of some CE is difficult to defend both from a legal and an economic point of view.

Another challenging aspect of costs is the definition of the cost of RM measures. Those that see extremely low costs of RM define the costs of reducing the temperature of the earth as those costs necessary to reduce the temperature once. However,

2 See for an excellent survey: James Fleming “Fixing the Sky: The Checkered History of Weather and Climate Control” (Columbia University Press, 2010).

3 Barrett, Scott, 2008. “*The incredible economis of geoengineering*” Enviromental and Resource Economics (39), 45-54.

4 RM technologies attempt to lower the temperature of the earth by reducing the solar energy that warms the earth. They thus try to compensate for the change in the radiation balance that has been caused by the continued emissions of greenhouse gases (GHGs). See e.g. Rickels et al. 2011. “Large-Scale Intentional Intervention s into the Climate System? Assessing the Climate Engineering Debate”. Scoping report conducted on behalf of the German Federal Ministry of Education and Research (BMBF), Kiel Earth Institute, Kiel.

the logic of RM requires to continue the RM activities for a very long time, since otherwise the temperature will start rising again.[5] Therefore, the cost of RM would be the cumulated, and discounted costs of RM measures until the measure can be stopped, for example, because the GHG concentration has been reduced sufficiently to make RM measures unnecessary. This means that the cost of RM can only be defined in a meaningful way by taking into account long-time scales and by recognizing the interplay between climate mitigation and the longevity of RM activities.

A final problem of evaluating the cost of CE measures relates to the global commons such as the oceans. There is a good likelihood that CE measures like iron fertilization will have unintended side effects for certain marine ecosystems. It would be hard to define the appropriate values for these side effects, the shadow prices of marine ecosystem services in economic jargon. First of all, it is very hard to put an economic value on some of the ecosystem changes that may accompany CE measures such as the changes in the composition of microorganisms that will take place with iron fertilization. And even if one were to come up with a method for calculating such effects, should the values attached to such changes by rich countries be used or should the shadow cost of low-income countries be used?

4. The Benefits of CE

There are numerous proposals in the literature for technologies with which CDR and RM can be done. They may turn out to be successful to different degrees. All of them share the problem as to how their success can be measured, although to largely different degrees. The assessment of the benefits of CE measures is, of course, crucial for a cost-benefit analysis.

At first sight this seems to be simple for RM measures: the reduction in the temperature of the earth is the goal. Consequently, the economic cost of climate change that would be avoided should be the correct measure. Yet, both steps are bound with difficulties. Measuring the effect of an RM measure on temperature is extremely difficult because the climate system's stochasticity. The effect of RM can only be determined with statistical methods and not through direct measurement. In fact, Loeb et al. (2007)[6] argue that 10 to 15 years of observation are necessary in order to detect a statistically significant impact. Consequently, the determination of economic benefits in terms of economic welfare would have to deal with the same uncertainty.

Similar problems arise with many of the CDR technologies. All measures which try to enhance the carbon uptake of the oceans cannot measure directly the amount of carbon that has actually been taken from the atmosphere and has been dissolved and transported into the deep ocean. Only model results can indicate the likely impact of such CDR technologies. For afforestation and for carbon capture the measuring of the carbon uptake is much easier, however.[7] If the cost-benefit analysis is to be used as a support tool for political decision making, the quality of the benefit calculations as well as the time frame in which such calculations can be made is of great importance. Both of these aspirations can hardly be fulfilled.

5. The Reference for Costs and Benefits of CE

One of the fundamental questions in cost-benefit analysis concerns the reference to which costs and benefits should be compared. Cost-benefit analysis was designed to compare relatively small projects or to assess a project relative to a situation where the project is not conducted. For CE activities this comparison is not at all straightforward. First of all, CE is defined as the large-scale interference into the climate system. This can hardly be considered a small project in almost all cases. As a consequence, one of the basic assumptions of cost-benefit analysis is violated, namely the constancy of all other aspects outside the project. To the contrary, many CE measures will change many economic activities through the repercussions of the large-scale projects. Such effects are not applicable to standard cost-benefit analysis but would require a complete integrated assessment framework with an economy-wide modeling approach, e.g. with computable general equilibrium models. Such an assessment goes far beyond traditional cost-benefit analyses. Large-scale afforestation is a good example for this problem. Afforestation of a small plot is well suited to cost-benefit analysis. However, doing the same analysis for the afforestation of Australia or the Sahara desert is essentially impossible.

The argument of low costs in favor of RM measures always relates to the cost of reducing emissions directly. However, these two cannot be considered separately. In fact, the costs of continued RM measures depend strongly on the CO_2 concentration in the atmosphere and therefore on the degree of emission control that is taking place simultaneously. The higher the GHG concentration in the atmosphere, the lower will be the cost of RM measures.[8] The above mentioned fact that RM measures need to be continued for potentially very long times has a very similar effect. The fewer emissions of GHGs will be reduced, the longer will RM need to be performed. As a consequence the costs of RM depend on the degree and path of emission control. Hence, an isolated assessment of costs and benefits of RM measures is faced with difficulties, especially if one considers that very large and continued interventions need to be considered if the radiation balance is to be influenced to a significant degree.

In summary, the conventional approach of cost-benefit analysis in which a project is evaluated under the assumption that all economic, social and environmental aspects not related to the project remain unchanged, is essentially impossible to be followed in the case of CE projects. One way out is to reduce the

5 Goes, M., Keller, K., Tuana, N., 2011. The economics (or lack thereof) of aerosol geoengineering. Climatic Change, 109, 719-744. Brovkin, V., Petoukhov, V., Claussen, M., Bauer, E., Archer, D., Jaeger, C., 2009. Geoengineering climate by stratospheric sulfur injections: Earth system vulnerability to technological failure. Climatic Change (92), 243–259.

6 Loeb, N.G. 2007. Multi-instrument comparison of top-of-atmosphere reflected solar radiation. Journal of Climate (20), 575-591.

7 For an overview see Rickels et al. (2011).

8 Klepper, G.; Rickels, W., 2012. The Real Economics of Climate Engineering. Economics Research International, in press.

admiration to cost-effectiveness analyses, where the benefits of CE are not determined. Instead, the assessment is reduced to the question at which cost a certain target such as reduction of the radiation balance in w/m^2 through RM or a reduction of the CO_2 concentration through CDR can be reached. These approaches are easier to manage but still complex enough such that no attempt has been made so far to assess the full social cost of global CE projects such as the reduction of global temperature or an accelerated uptake of atmospheric CO_2.

6. The Role of Uncertainty

Uncertainty in many dimensions is one of the most important features of CE technologies. Practically all CE technologies are based on theoretical considerations and very few have been tested on a small scale, none on a large scale. At the same time the understanding of the earth system that is to be manipulated by CE interventions is still insufficient to adequately model CE impacts. A cost-benefit assessment already lacks the data required to identify earth system changes. As these are the basis for the valuation exercises that transform changes in natural conditions into economic values, we are currently far away from being able to come close to an empirical cost-benefit analysis of most CE technologies.

These complexities of the earth system and the uncertainty about reactions to a CE intervention make it difficult to determine the required cost-benefit comparison, where the net benefits of a project are compared to the situation without the project. If a CE measure with long-term impact needs to be compared to an alternative evolution of the earth system without the intervention, it is probably very difficult to determine empirically whether a particular impact has been caused by the intervention or is just a result of the unpredictability of the evolution of the earth system. Such comparisons will therefore need to rely on modeling exercises which compare different scenarios. But the models used are themselves subject to model uncertainty. Dealing with all the uncertainties in a decision-making support tool needs to include a risk analysis. And such analyses surely go beyond the standard cost-benefit analysis.

7. Summary

We are currently far away from identifying the cost and benefits of CE measures. Several factors are responsible for this. Some are of particular importance for CE, others are generic to interventions into the climate system in general, whether it is climate mitigation or just the assessment of a continued increase in the concentration of GHGs in the atmosphere. The most important aspects that make it hard to assess cost and benefits of CE measures are the following:

- A standard cost-benefit assessment is designed for relatively small projects that have no large-scale repercussions on a national economic system or even the world economy.
- Assessing the costs of a particular CE activity is very complex because of the large-scale reactions of the earth system and possible wide-spread and complex changes in the economic system.
- The intervention into the earth system has aspects that are difficult to value in monetary terms, especially if they concern large-scale reactions such as large ecosystem changes.
- The long-term feature especially of the RM measures severely conflicts with the lack of predictability of economic developments over many decades or even centuries, thus making cost as well as benefit assessments impossible.

Despite the difficulties in dealing with the economic impacts of CE measures, it is necessary to get an impression of the economic aspects of CE, even if it is merely a rough understanding of the repercussions – positive as well as negative ones – that CE will have on the world economy. Standard cost-benefit analysis is not well suited for this endeavor. However, further research in the form of cost-effectiveness studies can provide many insights into the reactions of the economic system to CE activities. Even though it will take a very long time until we accurately know what the costs and benefits of CE are, different approaches of economic analyses will be able to provide vital information on the societal aspects of CE. These include, among others, scenario analyses on the basis of economy-wide models or game-theoretic approaches that look at the interaction of CE activities with other climate change policies.