The Paradox of Climate Engineering

Michael Zürn
Wissenschaftszentrum Berlin für Sozialforschung
Stefan Schäfer
Berlin Graduate School for Transnational Studies

Research Article

Abstract

Climate engineering technologies, sometimes also referred to as geoengineering technologies, attempt to ward off the worst effects of climate change by intervening in the global climate system. We see the potentials offered by climate engineering technologies in counteracting the threats of climate change but also take into account the risks that arise from the side effects of these technologies on natural, social and political systems. We find a paradox of climate engineering, which consists in the circumstance that exactly those technologies that are capable of acting fast and effectively against rising temperatures at comparatively low costs, are also the technologies that are likely to create the greatest amount of social and political conflict. To address this apparent paradox, we argue that an institutional setting for researching and potentially deploying climate engineering technologies is needed which creates a sufficiently high degree of social and political legitimacy and addresses a set of specified problems connected to climate engineering. We present a proposal for such an institutional setting that explicitly addresses these concerns.

Policy Implications

- Research on and potential uses of climate engineering technologies need to be coordinated internationally in a multilateral institutional setting.
- An international climate engineering agency should be created that coordinates and disseminates research on climate engineering.
- Research results should be evaluated by the IPCC.
- Decision-making on climate engineering should occur within the UNFCCC, where the states party to that convention should decide on norms and rules that govern climate engineering (regarding, for example, an upper limit for manipulations of the radiation balance, a uniform metric for making different responses to climate change comparable, and a time limited moratorium on field tests and deployments of climate engineering technologies).

1. International cooperation on engineering the climate?

A set of newly emerging high technologies, aimed at altering the global climate in an effort to counteract rising global mean temperatures, has recently begun to enter the scientific, public, and political debates. These technologies, referred to collectively as climate engineering technologies, attempt to offset global climate change by either reducing the concentration of CO_2 in the atmosphere (carbon dioxide removal (CDR)) or by reflecting sunlight away from earth (solar radiation management (SRM)). The amount of attention directed at climate engineering technologies will be magnified by the International Panel on Climate Change's (IPCC) fifth assessment report in 2014, which will address these technologies (IPCC, 2012).

Climate engineering promises a cheap solution for global climate change. At the same time, the unintended side effects on natural, social and political systems and the distributional consequences resulting from possible uses of these technologies are highly uncertain, and likely to involve 'unknown unknowns'. Therefore, it does not come as a surprise that the development and deployment of these technologies are contested.

In this contribution, we argue that the advantages of investing in these technologies are dependent upon certain institutional pre-requisites. On the one hand, we assume that it is useful to have a high leverage technology available if a climate crisis occurs. Climatic changes can be swift and ugly, creating unpleasant outcomes that are hard to tolerate. In such a case, adaptation is impractical (Victor, 2011, p. 185) and additional reductions of CO_2 emissions do not help since their effects would be felt only decades later. In the absence of sufficient emission reductions, climate engineering should be researched as a potential way to avoid such outcomes. On the other hand, we see a paradox of climate engineering that can only be overcome if a rightly designed international institution is in place. Only very few of the proposed technologies fulfill the promise of acting fast at a low price, making them suitable as responses to intolerable climatic changes. Many other climate engineering technologies are as cost-intensive and slow in effect as reducing CO_2 emissions is. Moreover, exactly those few technologies that promise to act fast at a low price would also bear the greatest risk of creating political and social resistance and conflict. It is for this reason that the successful development and deployment of climate engineering depends on an international institutional setting which is able to cope with the social and political side effects of climate engineering technologies through appropriate regulation.

We begin by examining the cooperation requirements for climate engineering from two perspectives. First, we ask what formal cooperation requirements climate engineering poses based on its implementation costs and its technical requirements. Which climate engineering options are amenable to unilateral or minilateral implementation and at the same time capable of quickly and significantly manipulating the global average temperature? It emerges that some – but far from all – climate engineering technologies can actually be implemented on a unilateral or minilateral basis with the goal of significantly influencing global mean temperatures (section 2).

Second, we expand this purely rationalist analysis in section 3 to include sociopolitical factors, asking what social and political side effects might arise from a unilateral or minilateral implementation of climate engineering technologies. Which technologies are likely to provoke social and political conflict in the absence of a legitimate multilateral approach to their research and implementation? We argue here that a unilateral or minilateral implementation of climate engineering measures could trigger a series of problematic consequences, which render the integration of research on and implementation of climate engineering technologies into a multilateral negotiation process advisable.

Sections 2 and 3 each result in a typology, which together display analytical power. Most typologies of climate engineering technologies are based on natural science concepts, such as the differentiation between CDR and SRM technologies. We offer two typologies to map climate engineering technologies which are based on social science concepts. The first typology shows which technologies are in fact amenable to unilateral implementation by laying open the requirements for this – they must be efficient (i.e., cheap and effective) and amenable to centralized implementation (as opposed to technologies that require implementation on the territories of many sovereign states to be effective). While this first typology explicates well known economic reasoning, the second typology uses sociological and political reasoning in order to show which technologies are most likely to create considerable social and political contestation and conflict. The fact that these technologies turn out to be the same as those that are amenable to efficient unilateral implementation in the first place lets us speak of a 'paradox of climate engineering'.

Given the paradox of climate engineering, we ask, thirdly, about the institutional prerequisites for the successful development and implementation of climate engineering technologies (section 4). We argue that a certain institutional design is necessary and desirable for internationally governing climate engineering. The institutional solution we propose aims at avoiding several problems that arise in the context of high leverage climate engineering: lack of social and political acceptance, moral hazard, slippery slope and prohibitively high termination costs.

2. The virtues of climate engineering?

Nobel laureate Tom Schelling, in an early piece on the topic, concludes that climate engineering will fundamentally change the way we think about climate change, reducing the issue to the simple question of who is going to pay for the costs of engineering the climate (Schelling, 1996, p. 306). We refer to the understanding that climate engineering provides a unilaterally implementable solution to the problem of rising global mean temperatures as the 'Schelling thesis'. Schelling's thesis regarding the politically simple implementation logic of climate engineering is ultimately based on the assumption of a vast efficiency of such measures from an economic point of view. This is vividly expressed by the title of an article by Scott Barrett, 'The Incredible Economics of Geoengineering', in which he states programmatically: 'In contrast to emission reductions, this approach [geoengineering] is inexpensive and can be undertaken by a single country, unilaterally' (Barrett, 2008, p. 45).

The central thesis of the unilateral resolvability of the problems associated with a rise in global mean temperatures through climate engineering is based on two assumptions. First, the costs of such measures must be so low that they can be burdened by an individual state unilaterally or by a small group of states (minilateralism). Additionally, their effectiveness must be so great that they enable the implementing state or group of states to significantly manipulate global mean temperatures. If a technology meets both of these criteria, we consider it to be highly efficient. Second, in order to be implementable uni- or minilaterally, climate engineering technologies need to be amenable to implementation on the territory of a single state, on a limited number of state territories, or in common spaces outside of national jurisdiction.[1]

The economic efficiency of climate engineering

Are climate engineering technologies indeed cheap and effective (i.e. efficient), and can they be deployed centrally in one location? Only if these conditions are met can a climate engineering technology be considered unilaterally or minilaterally implementable and potentially capable of 'totally transform[ing] the greenhouse issue' (Schelling, 1996, p. 305). In order to examine these propositions, we need to take into account the results of economic and natural scientific research.[2]

We operationalize the costs, effectiveness and amenability to centralized implementation of climate engineering technologies in the following way. Regarding costs, we are interested only in the direct costs that arise from the unilateral implementation of the measure in question, and not in external costs that may eventually arise in other locations – only the former are decisive in terms of the Schelling thesis. A climate engineering technology is considered highly efficient if it is not only affordable in this sense but also effective, meaning it must be capable of significantly changing global mean temperatures as a single measure in a relatively short period of time. Additionally, in order to be unilaterally implementable, a climate engineering measure must be amenable to centralized implementation. This means that it must be able to significantly change global mean temperatures when deployed on the implementing state's territory, on the territories of a small group of cooperating states or in common spaces outside of national jurisdiction. Should a climate engineering measure require decentralized implementation (i.e., in the territories of many states) in order for it to achieve a significant effect on global mean temperatures, then by its very nature it cannot be employed unilaterally with the goal of significantly influencing global mean temperatures, and would require a multilateral approach.[3]

Based on this operationalization, it emerges that far from all climate engineering technologies conform to the Schelling thesis. Only stratospheric particle injection and marine cloud brightening are both efficient and unilaterally implementable. All the other climate engineering technologies discussed in the literature are either:

- too expensive from the beginning, such as mirrors in space (see Robock, 2008; Royal Society, 2009, p. 45),
- too expensive when scaled up to an effective scale, such as afforestation of the Sahara and the Australian outback (see Ornstein, 2009), covering the world's desert areas with reflective material (see Royal Society, 2009) and enhancing rooftop reflectivity (see Akbari et al., 2009; Royal Society, 2009; Oleson et al., 2010),
- not effective as a single measure to stabilize global mean temperatures on a short timescale (enhanced weathering), or require decentralized implementation to be effective in that sense, such as direct air capture.

The only CDR measure that has by some been considered as potentially highly efficient is ocean iron fertilization. This technology is also amenable to centralized implementation. However, the extent of the effectiveness of this measure remains uncertain. Lenton and Vaughan (2009, p. 5593) argue that this measure is not suited for significantly influencing global mean temperatures on a short timescale. There is also uncertainty with regard to the costs of extensive ocean fertilization. In view of this, the efficiency of this measure can also be considered insufficiently high for it to be amenable to unilateral or minilateral implementation.

Figure 1: Typology 1 below sums up these findings. It emerges that only stratospheric particle injection and marine cloud brightening are amenable to unilateral or minilateral implementation. Large scale direct air capture, large scale afforestation, the enhancement of rooftop reflectivity, the modification of deserts to reflect more sunlight, ocean fertilization, reflectors in space, and enhanced weathering are either too expensive, not effective enough to significantly influence global mean temperatures, or require decentralized implementation, thus requiring the participation of many states and consequently a multilateral approach to their implementation. For example, measures such as the massive afforestation of the Sahara and the Australian Outback or the covering of the world's deserts with reflective material cannot be carried out unilaterally, but by their very nature require a multilateral approach. The implementation of such projects appears highly unlikely.

3. The social and political miseries of a unilateral or minilateral climate engineering policy

The thesis of a unilateral or minilateral solution to the problem of rising global mean temperatures through climate engineering is based on the rationalist theory of cooperation in international relations (compare Schelling, 1960; Keohane, 1984, Zürn 1992). The simplest version of this theory, from which the Schelling thesis is derived, is based on two premises. First, it assumes that states are the key actors in international politics and can act relatively autonomously, meaning without

Figure 1. Typology 1: Unilateral implementability of different climate engineering technologies.[4]

	High efficiency	Low efficiency
Central implementation possible	(1) ▪ Stratospheric particle injection ▪ Marine cloud brightening	(2) ▪ Ocean fertilization ▪ Space reflectors ▪ Enhanced weathering (land or ocean)
Decentralized implementation required	(3) ▪ Large scale direct air capture	(4) ▪ Large scale afforestation ▪ Enhanced rooftop reflectivity ▪ Desert modification

Source: Author.

consideration for transnational norms and actors or changing domestic interest constellations, only taking into account the commitments they made regarding international law. Second, it assumes that state interests with regard to a specific problematic situation are fixed and are not influenced by international negotiation processes. This approach is powerful for identifying intergovernmental interest constellations, but runs the risk of losing sight of the dynamic component of political interaction processes and the role of transnational norms and actors.

On the social and political consequences of a unilateral climate engineering policy

It can be expected that the unilateral implementation of a climate engineering technology will result in the comprehensive politicization of such activities. Decision-making processes, institutions and policy outcomes are considered politicized when they become the target of strong social mobilization with a high degree of contestation (on the politicization of international institutions, see Zürn, Binder and Ecker-Ehrhardt, 2012). Transnational norm entrepreneurs such as Greenpeace and other non-governmental organizations (NGOs) can mobilize a high level of political resistance by recourse to internationally recognized norms (Keck and Sikkink, 1998). It is especially likely for such a development to occur in Europe, since the potential for mobilizing the general publics against the introduction of new technologies has been traditionally high on the continent. Moreover, one can expect that the North-South antagonism in international climate policy would likely be intensified in case of unilateral deployment of efficient climate engineering technologies.

In the context of the Conference of the Parties to the CBD, the international community already submitted in part to the pressure exercised by several transnational NGOs with the support of some developing countries. The following was stated in a decision (UNEP/CBD/COP 10 Decision X/33):

> [The Conference of the Parties […] invites Parties and other Governments […] to […] ensure] that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting.

This very vague formulation and the legally non-binding nature of the CBD do not make it impossible for any state to field-test or implement climate engineering measures. Nevertheless, the inclusion of the topic in the convention is indicative of an increased awareness of climate engineering on the part of societal and political actors.

Growing social resistance against climate engineering can also be witnessed in other places. For example, the transnational NGO 'ETC Group' is active in the area of climate engineering. The ETC Group sets forth several arguments against climate engineering, including unequally distributed regional effects (ETC Group, 2009), the possibility of military use, and the potential role private sector interests could play (ETC Group 2010a, 37ff.). They also recur to international law in their rejection of climate engineering (for example to the ENMOD treaty in ETC Group, 2010b).

A further politicization of decisions regarding climate engineering and the institutions involved in making these decisions – which can already be witnessed in its beginnings – can be expected for several reasons. First, climate engineering fulfills all of the preconditions for the mobilization of social resistance that generally arise from the technocratic imposition of risk technologies in a global risk society (see Beck, 2008). Therefore, a strong connection can be expected between social movements in the implementing countries and a corresponding transnational protest movement. Second, in view of the non-involvement of technologically less powerful states, the hitherto unclear distribution of climate effects and the side effects arising from an implementation of climate engineering could evoke the North-South schism on a comprehensive scale and cause permanent damage to the United Nations Framework Convention on Climate Change (UNFCCC) process as a target of anti-hegemonic resistance (Rajagopal, 2003). Finally, both forms of resistance, social and political, could invoke general principles of international law (UNCLOS, Art. 195; Outer Space Treaty, right of consultation; Antarctic Treaty, peaceful purposes; Montreal Protocol, protection of the ozone layer; etc.), as well as the more specific provisions in the CBD and the London Convention and its Protocol. These norms do not contain clear provisions prohibiting climate engineering. They provide, however, a suitable normative anchor to serve as 'political opportunity structure' for resistance (della Porta and Tarrow, 2005; Tarrow, 2005).[5]

Moreover, dynamic processes of conflict escalation are conceivable. Third countries negatively affected by unilateral climate engineering could resort to radical opposition in the context of the UNFCCC process, and, in a very extreme case, even adopt counter measures – 'counter-climate engineering', (Lane, 2010). To this end, fluorocarbons could be deployed to counter the cooling effect from climate engineering, or black coal could be released to decrease the earth's reflectivity (see also Horton, 2011, p. 62).

In general, should environmental damage arise in a third country as a result of a unilateral climate engineering intervention, this is likely to lead to international conflict. Conflict might even occur in the absence of a clearly established causal link between environmental damage in a third country and a unilateral climate engineering intervention. A unilateral climate engineering intervention could thus be blamed for the occurrence of weather events even if it is not entirely clear that it was the climate engineering intervention that caused these events, substantially increasing the potential for international conflict.

In any case, the current absence of indications for a manifestation of interstate conflicts should not lead to predictions concerning their (un)likelihood in case climate engineering is implemented unilaterally. The regional effects of climate interventions will be unevenly distributed and thus are likely to lead to conflicts that could undermine the basis of cooperation on climate policy.

The social and political side effects likely to arise in reaction to a unilateral or minilateral implementation of climate engineering technologies bear witness to the legitimacy deficit inherent to such an approach, and can be expected to undermine the success of the implemented technologies. The most important circumstance out of which this legitimacy deficit arises is the fact that not only those states that proceed to intervene in the global climate are affected by this intervention. There is thus a lack of 'input congruency' (Zürn, 1998, p. 237) – not all parties affected by the intervention are involved in the decision-making process leading up to the intervention.

The specific social and political consequences of individual climate engineering technologies

In general terms we maintain that a unilateral or minilateral climate engineering intervention can have social and political consequences that undermine its chances for success. In order to undertake a more detailed assessment of this assertion, a second typology (Figure 2) of climate engineering technologies is introduced below. Here, climate engineering technologies are differentiated based on a political-legal perspective. We examine whether their implementation involves common spaces outside national jurisdiction (on this concept see Wolfrum, 1984) or state territories, and whether the undesired side effects resulting from their implementation are likely to remain local or tend to be global in nature.

First, we expect the social and political side effects of a unilateral or minilateral climate intervention to be especially strong in cases which involve the use of common spaces outside national jurisdiction, where no claim to sovereignty can be made. Second, we expect that measures producing undesired side effects that tend to be global in nature are conducive to strong politicization. On this basis, we can now identify the measures in field 2 as being at an especially high risk of undermining their own effectiveness by provoking social and political conflict when implemented unilaterally or minilaterally. This concerns exactly those measures that are sufficiently efficient to render their unilateral use in a climate

Figure 2. Typology 2: Extent of the social and political consequences of climate engineering unilateralism.

	Undesired side effects tend to remain local	Undesired side effects tend to be global in nature
Implementation occurs in common spaces outside national jurisdiction	(1) ▪ Ocean fertilization ▪ Enhanced weathering (ocean)	(2) ▪ Mirrors in space ▪ Stratospheric aerosols ▪ Marine cloud brightening
Implementation occurs on state territory	(3) ▪ Air capture ▪ Enhanced weathering (land) ▪ Enhanced rooftop reflectivity	(4) ▪ Large-scale afforestation ▪ Albedo modification of deserts

Source: Author.

emergency possible in the first place. In other words, precisely those measures which we identified above as potentially unilaterally or minilaterally implementable are those that incorporate the greatest potential in terms of generating politicization and resistance. Here, the explanatory character of our second typology emerges: even those few technologies that conform to the Schelling thesis are unlikely to be successfully implemented by a single state or a small group of states, due to their inherent conflict potential. This is what we label the paradox of climate engineering (see also Rayner, 2010).

This paradox is what seems to drive NGOs that oppose climate engineering. 'Hands Off Mother Earth' (HOME) is an association of different organizations which is exclusively devoted to resistance against climate engineering technologies.[6] Its objective is '[…] to build a global movement to oppose real world geoengineering experiments […]' (HOME, 2011a). The climate engineering technologies mentioned on the HOME website and against which the organization's protest is directed are the production and storage of biochar, the introduction of sulfur particles into the stratosphere, marine cloud brightening and the storage of CO_2 in the ocean through nutrient fertilization (HOME, 2011b). With the exception of the production and storage of biochar, these are all measures that have extensive trans boundary effects and can be implemented in common spaces outside national jurisdiction.[7]

This means in turn that *climate engineering technologies which are not amenable to unilateral or minilateral implementation are likely to generate less social and political conflict*. The modification of rooftops, afforestation, the enhancement of natural weathering and air capture offer a comparatively low conflict potential. As yet, no significant social or political mobilization processes have arisen in opposition to these proposals. Also, proposals for scaling up originally local measures to increase their leverage, such as 'greening' the Sahara and the Australian outback or covering the world's deserts in reflective material, have not led to notable reactions. This is likely to be to a large degree due to the clear requirement of multilateral action on such projects, which makes them appear less threatening, and the associated fact that such projects are highly unlikely to be realized.

The examination of the social and political consequences of individual climate engineering technologies shows that climate engineering faces a seemingly irresolvable paradox. The promise of a fast and highly effective solution to the problems associated with rising global mean temperatures, which is so cheap that it can be implemented by a few states on behalf of all humanity, is provided by only two climate engineering technologies: stratospheric particle injection and marine cloud brightening. However, these are precisely those technologies that are likely to lead to particularly vehement politicization and far-reaching social and political resistance with potentially devastating consequences for the UNFCCC process.

4. Overcoming the paradox: Proposal of an institutional design for the governance of climate engineering technologies

In spite of the paradox of climate engineering, research on high leverage climate engineering technologies seems in principle advisable for several reasons. Due to the high costs arising from the necessary transition to a carbon neutral economy, all options that could contribute to reducing the costs of this transition should be explored. Furthermore, the difficulty of achieving international agreement on reducing emissions and the longevity of greenhouse gases in the atmosphere make it desirable to have an option available that allows us to shave off the worst effects of climate change.[8] Most importantly, some authors have suggested that climate change might occur dramatically and abruptly if so-called 'tipping points' are passed (on tipping points in the climate system see Lenton et al., 2008). If researched today, highly effective climate engineering technologies would be made available for cases of 'climate emergencies' (Victor, 2011, chap. 6).

However, research on and implementations of climate engineering technologies can only overcome the paradox and produce the desired results if four potential side effects are addressed. First, research on climate engineering technologies needs to possess a sufficient amount of social and political acceptance. In the absence of this acceptance, negative social and political reactions are likely to preempt the development of a possibly important technological option to counteract climate change, which might be needed in the future. Second, 'moral hazard' effects need to be avoided. This term refers to negative effects of research on or implementations of climate engineering technologies on emission reduction efforts. Third, the slippery slope effect needs to be restricted. This describes situations in which conducting research on climate engineering technologies might increase the likeliness of deployment. For example, this can refer to the fear that an institution conducting research on climate engineering measures would develop an interest in conducting further research and eventually pressure for the use of climate engineering technologies, even in the absence of a situation that would warrant such a course of action. Finally, since the premature abandonment of an ongoing climate engineering intervention might have catastrophic consequences, the fourth criterion consists in avoiding such premature abandonment as far as possible and in minimizing the risks associated with it. This has also been referred to as the termination problem. Research on and possible implementations of climate engineering technologies thus require an *institutional setting* which creates a sufficiently high degree of social and political acceptance, specifically addresses the moral hazard and the slippery slope effect, and ameliorates the termination problem. The fulfillment of these criteria – each of them mostly discussed in separate discourses – is necessary to overcome the climate engineering paradox. Thus, an institutional solution is offered to overcome the paradox.

A multilateral approach to climate engineering would be capable of reducing these side effects of climate engineering technologies. Below, we propose six features for a multilateral institutional setting that directly address the criteria developed above in the context of the paradox of climate engineering, identified in sections 2 and 3.[9] This institutional setting draws on core elements of the existing regime complex for international climate policy (Keohane and Victor, 2011), including the UNFCCC, the IPCC, and the Kyoto Protocol.[10]

We develop our proposal for an appropriate institutional setting against the background of analyses about the effectiveness of international environmental regimes (Haas et al., 1993; Young, 1999; Miles et al., 2001, Breitmeier et al., 2006) and corresponding research on international institutional design (Ostrom, 1990; Koremenos et al., 2001). We also take into account the existing literature on the multilateral regulation of climate engineering.[11] Virgoe's (2009) considerations on the international regulation of climate engineering come closest to the proposal presented in the following section. He sees the danger of strong international tensions emerging in the event of a unilateral deployment, which would result from the lack of legitimacy inherent to such an approach. A consortium of states on the other hand would be exposed to a conflict of objectives between the ability to act on the one hand and the requirement of achieving a high degree of legitimacy on the other, and would be unstable in the long run. He thus opts for a multilateral framework. Such a multilateral framework can in our view contain minilateral initiatives by a club of states capable and willing to do research, as long as this is embedded within a larger framework (see Victor, 2011, chap. 7). Our proposal consists of three principles and six components. Three institutional principles must guide research and deployment of climate engineering in order to overcome the four potential side effects identified above:

- *transparent coordination* of efforts should dominate research and deployment competition in order to achieve social and political acceptance, and to ensure that a potential future deployment takes place based on the best available scientific knowledge;
- *institutional integration* with existing climate policy should dominate institutional fragmentation in order to ensure that past achievements in setting emission reduction requirements do not suffer, and that future efforts to this end are not preempted, thus avoiding moral hazard;
- a clear *distinction between research and deployment* is needed to allow for political decisions after sufficient knowledge is available, thus avoiding slippery slope effects and the termination problem.

More specifically, we see six components of such an international institution as necessary.

1. An *international climate engineering agency* should coordinate research into individual climate engineering

technologies.[12] To this end, a coalition of states needs to be formed that is prepared to finance and carry out the corresponding research in a transparent manner. To ensure incentives to participate, member states should be able to credit contributions against CO_2 efforts (see also component 4). To ensure broad acceptance, information on funded projects needs to be made available to the public, perhaps through an online registry. While members of the club should be asked to finance their climate engineering research efforts exclusively via the agency, we do not expect there to be no research on climate engineering outside of agency-funded projects; however, the availability of funding *per se*, paired with the high visibility and legitimacy gains associated with agency-funded research and the associated assurance of a smooth research process, should provide a strong incentive for scientists to engage with the agency and apply for funding. Researchers conducting research projects on climate engineering that are not funded through the agency should be encouraged to also register their projects, leading to a strong norm of transparency. This will create a vibrant research program that sets standards and norms for research on climate engineering. In sum, the agency is intended to ensure the availability of funding for climate engineering research, increase the transparency of research, contribute to the development of norms and standards in climate engineering research, and to conduct institutional oversight according to a regulatory code that is to be developed.[13] This would generally increase the legitimacy of climate engineering research.

2. The assessment of the research outcomes, however, should be undertaken by the Intergovernmental Panel on Climate Change (IPCC). Three reasons speak for this task sharing arrangement between the IPCC and the proposed climate engineering agency. First, due to the enhanced consultation commitments of the IPCC, the range of the actors involved is considerably wider than in the proposed climate engineering agency, the members of which are to be drawn from countries actively involved in research. Charging the IPCC with the assessment of research results would thus increase the social and political acceptance of this research.[14] Second, the assessment of research into climate engineering on the one hand and of research into climate change more generally on the other would occur in an integrated manner, thus also taking into consideration climate policy alternatives and the overall problem of climate change. This would reduce the risk of climate engineering being perceived as an alternative to emission reductions, thus reducing the risk of moral hazard. Most importantly, the institutional interest of a climate engineering agency in increasing its own standing and relevance through positive evaluations of climate engineering research would be preempted, thus reducing the risk of a slippery slope effect. Very much in line with this suggestion, such an assessment of climate engineering research will be part of the IPCC's Fifth Assessment Report (AR5). The IPCC's Expert Meeting on Geoengineering also suggested drafting a special report on the topic.
3. On the basis of the IPCC assessment, the member states of the UNFCCC should then proceed to make decisions regarding norms and rules for governing climate engineering.[15] These norms and rules should govern which technologies are to be further developed and made ready for deployment, which field research will be allowed for this purpose, and which technologies are to be deployed under which conditions. The checks and balances created by an institutional setting in which the climate engineering agency functions as research coordinator, the IPCC as evaluator and the UNFCCC as political decision maker allows for a clear separation between research and deployment, thus helping to avoid slippery slope effects. While the UNFCCC process, including the IPCC, seems for many discredited after the ongoing failure to achieve a strong international climate regime to reduce CO_2 emissions, there is no alternative for multilateral norms and rules than agreement by the member states. Moreover, by introducing climate engineering to the package that is negotiated, the current deadlock could be overcome since it strengthens those states that have an interest in acting on climate change and broadens the portfolio of available measures. It thus creates new possibilities for issue-linkage, introducing to the negotiations novel responses to climate change that are not (yet) strongly politicized.

The following three components provide further suggestions for potential rules that should guide such an institutional effort. Such rules will need to be worked out in more detail, of course.

4. To avoid moral hazard and a one-sided focus on climate engineering, climate engineering technologies should be made comparable to conventional emission reductions by *installing a uniform metric for comparison*. Since climate engineering technologies, and especially SRM technologies, are not of themselves comparable to mitigation due to the huge differences in effectiveness and costs, this needs to be achieved via an external factor. A price conversion mechanism thus should be created which compensates for the higher effectiveness of climate engineering technologies where this is appropriate. The contributions of states to the costs arising from the development and deployment of climate engineering technologies should thus be measured according to how much the

same contribution would have achieved when invested in conventional mitigation, thus adjusting the comparison between the costs of mitigation and the costs of climate engineering according to the desired goal of avoiding a use of climate engineering as a substitution for mitigation. This would create cost equivalence, as opposed to effectiveness equivalence, between different climate engineering technologies and conventional emission reductions.

As a result, it would be possible to extend the portfolio of climate-effective measures whose implementation can be accredited to the reduction targets laid down in the Kyoto process in the future. The implementation of direct air capture, enhanced natural weathering, and increasing the reflectivity of rooftops could thus be accredited to international reduction targets,[16] as is already the case with afforestation.[17] Within this uniform metric, CO_2 could be selected as a reference measure, as already applies to the conversion of the climate effects of other greenhouse gases such as CH_4 or N_2O. This is intended to preempt an interpretation of climate engineering technologies as an alternative to emission reductions by ranking their effectiveness adjusted to the effectiveness of conventional mitigation. Similarly as an upper limit on conscious interventions into the radiation balance (see component 6), this measure would contribute to an understanding of SRM as a transition technology capable of helping societies avoid the worst effects of global climate change without substituting for mitigation.

5. To limit the risk of a slippery slope effect, a time-limited moratorium on the implementation and field testing of climate engineering technologies should be installed. The technologies in field 3 of typology 2 (those which can be implemented on sovereign territory and whose effects remain local) need to be exempted from such a moratorium. Research on all other technologies would be affected by this measure. The moratorium needs to be time-limited so as not to prematurely prescribe an institutional blockade.[18] However, so as not to initiate a slippery slope effect after the moratorium has expired, field testing and deployment would still need to follow the rules set down by the UNFCCC.
6. In order to counteract the termination problem, a state should be obliged to significantly *increase its emission reduction efforts should it abandon a multilateral climate engineering effort*. In order to keep the problem in a feasible range, a possible base rule could be to decide not to alter the radiation balance by more than a certain value, such as 1 W/m^2. This would defuse the termination problem to a certain extent, since the pressure to reduce greenhouse gas concentrations would remain stronger than under a scenario in which forcing is offset to a larger degree. This would point in the direction of an understanding of SRM as a means to shave off the worst effects of climate change, rather than as a complete substitute for emission reductions. In addition, this would likely reduce the potential extent of negative side effects on natural systems in comparison to a scenario in which a stronger intervention is undertaken. Coupling emission reduction requirements to the exit option of a multilateral climate engineering intervention would provide a strong legal basis for pressuring individual states to reduce their emissions. The costs associated with the avoidance of accelerated climate change in the case of premature termination could thus be imposed on the countries that were involved in driving the climate engineering intervention.

Conclusions

The above analysis shows that an institutional setting for the governance of climate engineering research and implementation is desirable which ensures sufficient international and transnational social acceptance and integrates climate engineering with existing climate regulations in such a way that negative social and political effects can be avoided. To this end, we presented a recommendation which proposes the creation of a climate engineering agency for coordinating and conducting research, an assessment of research results through the IPCC, the definition of norms and rules governing climate engineering through the member states of the UNFCCC, installing a uniform metric for creating comparability between SRM, CDR and conventional mitigation measures, installing a time-limited moratorium on field testing and deployment of certain technologies, and the definition of terms for phasing out a climate engineering intervention. If climate engineering is deployed in the absence of such a multilateral institutional framework, it is likely that the problems associated with lacking social and political acceptance, moral hazard, slippery slope, and premature termination fully manifest themselves.

Notes

We would like to thank Peter Haas, Alan Robock, David Victor and Oran Young for critical comments on an earlier version of this piece. We also greatly benefitted from the collaboration with our colleagues involved in the drafting of the scoping report on climate engineering (Rickels et al., 2011), commissioned by the German Federal Ministry of Education and Research, and from the discussion of an earlier version of this piece in the colloquium of the research group Transnational Conflicts and International Institutions at the Social Science Research Center Berlin.

1. In addition, the Schelling thesis assumes that international law does not formally stand in the way of such a solution. Legally binding prohibitions on the use of climate engineering technologies do indeed not exist in international law. International law however does not explicitly allow the use of climate engineering technologies either. We thus concur with Wiertz and Reichwein (2010, p. 17) that whether and to what extent international law applies to research on and uses of climate engineering depends on the political interpretation of existing treaties (see also Virgo, 2009; Zedalis, 2010; Proelss and Güssow, 2011).
2. We thus inherit the uncertainty of the respective assessments. While it has been shown by natural scientists that individual climate engineering technologies are capable of manipulating earth's energy balance on a large scale, and economists have shown that the direct costs for these technologies appear to lie significantly below the costs of conventional emission reductions, these results remain freighted with large uncertainty.
3. Via the criterion of effectiveness we operationalize what is referred to in the natural scientific literature as 'scalability' (Caldeira and Keith, 2010, p. 60).
4. In this typology, the efficiency criterion refers exclusively to the capability of a climate engineering technology to significantly influence global mean temperatures on a short timescale (effectiveness) at relatively low costs (affordability). Measures whose efficiency is here listed as being 'low' can thus nevertheless, on a medium to long timescale and in combination with emission reductions, be part of a portfolio system of policy measures aimed at reducing the risks that result from rising global mean temperatures, and should not be disregarded. Lenton and Vaughan (2009, p. 5539) state that '[s]trong mitigation, combined with global-scale air capture and storage, afforestation, and biochar production, i.e. enhanced CO_2 sinks, might be able to bring CO_2 back to its pre-industrial level by 2100 […]'.
5. As mentioned before, the legal situation is starkly underdetermined and thus allows the use of international law for very different positions.
6. The HOME campaign currently lists 107 organisations as 'allies and endorsers' on its website (HOME, 2011c).
7. However, even resistance against the production and storage of biochar is justified by referring to the large area that is necessary for the use of this technology, thus indirectly conforming to our thesis: 'The biggest danger of biochar for geoengineering, however, is scale. Hundreds of millions of hectares of land likely needs to be turned over to new plantations in order to produce the quantities of biochar many talk about' (HOME, 2011d).
8. Biermann et al. (2010) and Victor (2011) together provide for a very good overview on the efforts and problems in creating effective climate governance.
9. While the inclusion of core elements of the existing international regime complex for climate change and the fact that certain aspects of our institutional proposal are already being implemented, such as the IPCC assessment of climate engineering technologies in AR5, have the effect that the realization of our proposal does not appear unfeasible, the issue of feasibility is not further explored here. For a detailed exploration of the feasibility of this institutional proposal, see Schäfer (forthcoming).
10. We are aware that some commentators consider this to be counterproductive, arguing that the introduction of climate engineering into this existing institutional environment will provide the death blow to international cooperation on climate policy. We do not believe this to be the case for the following two reasons. First, the IPCC is capable of providing highly credible assessments of state of the art research, thus substantially increasing the perceived legitimacy of climate science. Subjecting climate science, and by extension also research on climate engineering to IPCC assessment, can greatly enhance trust in the results of such research and in policy changes and decisions on research project funding that are made on the basis of these results. Second, some critics consider the UNFCCC process too feeble to cope with the potentially conflicting results of introducing climate engineering to the ongoing negotiations. However, we consider the opposite to be at least as likely. Through the introduction of climate engineering into negotiations on climate policy, these discussions could be reinvigorated through the possibility of drawing up a portfolio approach to climate change management that does not rely exclusively on voluntary emission reductions and the transfer of funds for adaptation. Climate engineering could thus depoliticize the current negotiations on climate change management by providing an additional measure that is not (yet) strongly politicized itself.
11. For example Barrett (2008); Bodansky (1996); Carlin (2007); House of Commons (2010).
12. This would be another environmental assessment agency. Such agencies have increased strongly in number during the past 10–15 years (see Mitchell et al., 2006). Along the same line, Biermann and Siebenhüner (2009, p. 319) point out that international secretariats can act as negotiation facilitators, capacity builders, and knowledge brokers.
13. Points of departure for developing such a regulatory code can be found in the 'Oxford Principles', in SRMGI (2011), and in Morgan and Ricke (2010).
14. While the legitimacy of the IPCC is regularly questioned, this has in the past always led to reform and consequently to increases in the perceived legitimacy of the institution. Current discussions need to be seen in this broader context (Beck, 2010). Victor (2008) argues that the IPCC is not suited for assessing the results of research on climate engineering since it focuses on 'consensus science', while the 'improbable, harmful and unexpected side effects' are what counts in climate engineering. While Victor's arguments for an alternative approach to climate engineering research assessment are convincing per se, we argue that the legitimacy gains an IPCC assessment of climate engineering entails and its expected catalytic effects for UNFCCC negotiations weigh up the tradeoffs. Apart from these considerations, it has already been decided that AR5 will prominently address climate engineering research. The IPCC 'Expert Meeting on Geoengineering' also suggested drafting a special report on the topic in the near future, very much in line with our suggestions.
15. In fact, most of the regulatory proposals in the literature support a solution within the UN system (see e.g. Barrett, 2008; Virgoe, 2009; House of Commons, 2010). Bodansky (1996, pp. 318ff) criticizes the low level of authority of existing institutions and considers the creation of a new institutional setting desirable.
16. A similar view is expressed by the The Royal Society (2009): 'A question for all CDR methods is whether they will be eligible for certification under the KP (or its successor instrument) under the clean development mechanism or joint implementation'.
17. National afforestation measures can be offset against emission reduction commitments within the framework of the Kyoto

Protocol. Should an international accreditation scheme emerge, this should also apply to afforestation measures being financed in other countries.

18. This distinguishes our proposal for a moratorium from Kraemer's (2010), which suggests a moratorium as a component of a political strategy to prevent climate engineering altogether.

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Author Information

Michael Zürn is director at the WZB (Social Science Research Center Berlin) and Professor of International Relations at the Free University Berlin.

Stefan Schäfer is a project scientist at the Institute for Advanced Sustainability Studies (IASS). At the time of writing, he was a PhD student at the Berlin Graduate School for Transnational Studies (BTS).

