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Review

Impacts, risks, and governance of climate engineering

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Abstract

Climate engineering is a potential alternative method to curb global warming, and this discipline has garnered considerable attention from the international scientific community including the Chinese scientists. This manuscript provides an overview of several aspects of climate engineering, including its definition, its potential impacts and risk, and its governance status. The overall conclusion is that China is not yet ready to implement climate engineering. However, it is important for China to continue conducting research on climate engineering, particularly with respect to its feasible application within China, its potential social, economic, and environmental impacts, and possible international governance structures and governing principles, with regard to both experimentation and implementation.

Keywords: Climate engineering; Environmental impacts and risks; International governance

1. Introduction

Climate change is real and of critical importance. There is a 95% chance that global climate change has attributed to human factors (IPCC, 2013). The 450×10^{-6} scenario, given by IPCC AR5, is based on large-scale bioenergy and carbon capture and storage (CCS) utilization. The risk of human-induced climate change requires the management of our activities. The main conclusion from the Stern Review (Stern, 2006) is that the benefits of strong, early climate change mitigation actions will far outweigh the costs of doing nothing. However, global negotiations and mitigation actions on climate change have been slow, and these approaches lack efficiency. Geoengineering or climate engineering is expected to play a significant role in mitigating global temperature increases; however, the relative impacts and risks of these engineering practices need to be closely examined.

China, as an emerging economy, attracts more and more attention with respect to its role in international affairs. Some Western journalists and scholars have stated that China is one of the countries with the capability and potential willingness to implement large-scale climate engineering (Anderson, 2012). Furthermore, China has long been implementing modifications that increase risk resilience, although China does encounter obstacles and difficulties in traditional mitigation areas. Yet, does this mean that China is ready for climate engineering?

At present, the scientific basis for climate engineering is not sufficiently clear to elucidate an obvious technological approach. However, it is critically important to consider the ethical and governance issues arising from any possible climate engineering experimentation or implementation. It is also necessary to provide a clear message to the international and domestic communities on the Chinese perspective on this issue. The following sections will examine the definition,

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impacts and risks, and governance issues to establish a Chinese perspective on the future governance of climate engineering. Finally, this manuscript will present an unambiguous recommendation on China's principles and position with regard to climate engineering.

2. Definition

Climate engineering, mostly known as geoengineering, is defined as "human's planned measures to cope with climate change by altering the environment on the Earth on a large scale" (RS, 2009). More recently, scholars have decided that geoengineering is too ambiguous as people sometimes confuse geoengineering with the building of large dams or tunnels or with the undertaking of massive engineering projects that change the global environment. Scientists are instead choosing to use the term climate engineering to keep their discussion within the bounds of climate change. Climate engineering describes a diverse and largely hypothetical array of technologies and techniques for the intentional manipulation of the global climate in order to moderate or forestall the (most severe) effects of climate change (Lawrence, 2014). Climate engineering includes a grab-basket of technologies that generally address carbon dioxide removal (CDR) and solar radiation management (SRM). From these classifications, we can infer that climate engineering aims to manipulate the global temperature by changing solar radiation or atmospheric carbon concentrations, i.e., by modifying the Earth's albedo. Irrespective of whether they are fast or slow, all these techniques have the potential for significant environmental impacts and risks.

3. Impacts and risks

Climate engineering involves large-scale interventions in complex, dynamically interacting systems that are not adequately understood. In other words, we have no way of accurately predicting the impacts of climate engineering applications: they could easily compound the problems we are already facing because of increased climatic instability (Biofuelwatch and Econexus, 2014). It is not possible to quantify or even identify the relative environmental, social, political, legal, and economic risks at this time, given the current state of our knowledge on our complex global system. Both the uncertainties in modeling climate change and the potentially far-reaching consequences of climate engineering currently make it impossible to provide reliable, quantitative statements about the relative risks, consequences, and benefits of albedo modification, let alone the benefits and risks to specific regions of our planet (NAS, 2015).

It is obvious that prior to the further consideration of climate engineering, with its substantial potential environmental impacts and risks, the inherent uncertainties need to be re-evaluated. If the potential impacts and risks of implementing any type of climate engineering are higher than doing nothing, the discussion needs to cease. Halting, or at least slowing, the implementation of climate engineering would allow for consideration of the three pillars of sustainable development: social, economic, and environmental impacts. Simultaneously, there are ethical risks.

The potential impacts for climate engineering can be divided into three dimensions: 1) direct environmental impacts, 2) indirect environmental impacts, and 3) indirect impacts on climate mitigation politics and policies.

With respect to the first dimension, direct environmental impacts, there are SRM projects that release sulfates into the atmosphere, chemically polluting the air. The observed effects from volcanic eruptions include stratospheric ozone loss, changes to precipitation (both amounts and patterns), and likely increased growth rates of forests, due to an increase in diffuse solar radiation (NAS, 2015), and provide insight into potential direct environmental impacts from albedo modification. In addition, there are ocean fertilization projects that propose pouring iron powders into sea, which may lead to eutrophication. CCS projects aim to change the environmental conditions of geological structures, but they all have the potential risk of carbon dioxide leakage. However, these projects are all REDD+[1], which could benefit the ecosystem.

For the second dimension, indirect environmental impacts, climate engineering could lower the global mean temperature; however, it could also change local temperatures and precipitation levels, which could be detrimental to agriculture and established ecosystems. Further complicating the matter is the potential for regional disparities in the distribution of benefits and risks (Kravitz et al., 2011; Moreno-Cruz et al., 2012). In fact, computer-modeled SRM interventions result in either excessive cooling in the tropics or excessive warming at high latitudes, or both (CBD, 2012). Still, not all predicted precipitation changes are offset: models of the SRM world fully counter anthropogenic radiative forcing and consistently show a slowing of the hydrological cycle, with an up to 2% decrease in global mean precipitation. This change in precipitation is predicted to be most pronounced over land and within the equatorial regions, so, among the regions containing the most biodiversity (CBD, 2012). However, fast-food climate engineering projects only focus on lowering the global mean temperature; they leave the environmental problems caused by conventional fossil energy usage unfixed. SRM methods do not seek to reduce the atmospheric concentrations of anthropogenic CO_2, so the process of ocean acidification would continue.

For the third dimension, impacts on politics and policies, if a country's government believed that climate engineering techniques could reliably curb global warming, they would most likely change their future development strategies. For example, a so-called green transformation of the energy system would seem irrational, and further investment in renewable energy would be tabled.

[1] REDD+ is the abbreviation for reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks.

4. Governance

The implementation scope of climate engineering solutions can be grouped into global commons-based classifications, these include atmospheric, oceanic, outer spatial, and territorial projects. For instance, the implementation of the SRM called space mirror, in which SPI would be injected into the stratosphere and resulting in cloud whitening, is an example of a global-commons project, while roof whitening and desert mirror implementation would be a (national) territorial project. Similarly, CDR and ocean fertilization are global commons-based projects, while afforestation and CCS would be grouped within the national territory classification.

Many of these potentially usable technologies are regulated by international or national environmental laws, while other technologies are not addressed. According to the scientific report provided by the Conventional of Biodiversity (CBD, 2012), technologies such as ocean fertilization are under regulated by the London Protocol, while other technologies, including solar radiation management, are still unregulated. A clear understanding of the potential impacts and risks is foundational to creating appropriate governance. A well-designed, transparent mechanism is crucial for regulation.

Climate engineering not only impacts the air, water, and land, it also has potential implications for economic development, political maneuvering, and social evolution. Relevant experiences with similar technologies, such as nanotechnology and transgenic technology, resulted in louder disputes with respect to their governance than the implications of their usage. As mentioned previously, climate engineering is a mixed basket of technologies that aim to manipulate the global temperature. Thus, the governance of climate engineering technologies, at this current stage, is provided by different international, national, and regional legislative frameworks.

According to CBD (2012) on climate engineering and its social impact, there is an increasing volume of literature that addresses the social dimensions of geoengineering (Banerjee, 2009; Victor et al., 2009; Galaz, 2012). These issues relate to geoengineering ethics, governance, and socio-politics, and have also been discussed within the geoengineering research community. This is exemplified by the Oxford Principles (Rayner et al., 2009). CBD (2012), which provides an overview of the existing regulations and institutional arrangements that relate to climate engineering governance issues. In Table 1 we can see that most of the CDR technologies are regulated under modern international law, to avoid cross-boundary conflicts, while most of the SRM technologies have governance gaps, preventing their widespread regulation.

The current global governance structure for climate engineering is insufficient to mitigate the potential risks or compensate for intentional or unintentional climate engineering mis-implementation. Due to all of the aspects and potential impacts of climate engineering, no single international legal instrument provide comprehensive coverage. Integration and coordination among multiple international regulations is essential. The United Nation Framework Convention on Climate Change (UNFCCC) has endorsed CCS as one of the most effective global warming mitigation measures, yet it has not opened the gates for further discussions on climate engineering, neither with respect to its technology, nor its governance.

5. A Chinese perspective

China is under prodigious pressure to implement climate mitigation. The conventional mitigation practices are not only economically expensive, but they also results in significant social impacts. Climate engineering measures with relatively small impacts and risks may be a reasonable alternative choice. However, there is no concrete analytical data on the potential costs associated with utilizing climate engineering technologies. “In practice the information available on costs is extremely tentative and incomplete, and only order-of-magnitude estimates are possible”, as stated in the Royal Society report (RS, 2009). Even the most advanced studies, conducted on an international level, could not provide such data, and Chinese researchers have just recently started to delve into climate engineering. China has a history of implementing large-scale engineering projects to change its geological conditions and local weather, in order to combat natural disasters. These projects, including artificial afforestation, the South Water to North project, and the Three Gorges projects, were not aimed toward changing the global climate. These projects, as well as their impacts and risks, were all very well estimated prior to their implementation. For example, in order to implement the Three Gorges projects, based on previous work since 1950, Yangtze River Basin Comprehensive

Table 1
Climate engineering technologies and their potential regulation.

Technology		Relevant treaties and potential gaps	Note
SRM	Space-based reflectors	Space law (Outer Space Treaty)	No specific rules or guidance
	Stratospheric aerosols	Montreal protocol	Only applies to the gravity of actual impacts
	Cloud reflectivity		No global treaty applies
	Surface albedo		No global treaty applies
CDR	Ocean fertilization	UNCLOS; LC/LP	
	Enhanced weathering (ocean)	UNCLOS; LC/LP	
	Ocean CCS	UNCLOS; OSPAR in the Northeast Atlantic	
	Ocean biomass storage	UNCLOS; LC/LP	Only with guidance for the dumping of organic materials
	Subsurface CCS	LC/LP; OSPAR	Rules under development

Source: CBD (2012).

Utilization Plan Highlights Report was finished in 1959 (YRBPO, 1959) and was revised in 1988 (YRBPO, 1988). Scientists and engineers repeatedly investigated the feasibility and importance of the development of the Three Gorges, and they also pay a lot of concerns on the response measures on the potential floods and other challenges caused by electricity production. Nevertheless, in 1992, on the requirement of the Central Government, more than 400 scientists, engineers and experts in this area cooperate to do another assessment report, Yangtze River Three Gorges Project Feasibility Report (CTGPC, 1992), to update the data and cases for a reliable and feasible estimation of the actual implementation. And no earlier than 1994 did the work of the Three Gorges finally started. For another example, China modifies its weather to avoid agricultural disasters, and weather modification has been supporting the Chinese agricultural production for many years (Zhu et al., 2015). China is well equipped for weather modification and has already provided international cooperation to assist other countries in combating droughts and other agriculture disasters (Guo, 2009). From the scientific research, technological innovation, equipment installation, and management development, China's weather modification projects have accumulated extensive experiential data (Liu, 2015). However, China has also invested substantial financial and human resources into its previous engineering research, including progress monitoring. The relevant risks and impacts were almost completely controlled, and adequate compensation was provided to mitigate overflow effects.

The Chinese governing structure does not place such priority on climate engineering. Until now, China has had no sufficient scientifically-research basis to implement climate engineering. There are a few Chinese researchers and scholars who have been following the development of climate engineering, although national and ministerial projects only commenced in 2015. Other countries, however, particularly the U.S., the UK, and Germany, began their research on climate engineering at a much earlier date and have been furthering its discussion. Harnisch et al. (2015) explained that scientists have played a leading role in the initiation of the climate engineering debate, especially within the UK, where scientists have proactively brought climate engineering onto the national political agenda. Scientists in Germany have been the source of a more skeptical political stance toward climate engineering. These examples highlight the instrumental role that scientists play in influencing their country's environmental politics. In contrast, the U.S. executive branch has thus far taken no official stance on climate engineering, although this may be a result of the divisive U.S. national politics with respect to climate change.

Compared with the U.S., the UK, and Germany, China is merely a follower on this topic, both from the aspects of natural scientific research and social regulatory study. China's current relevant research basis is far too small to support a well-supported national strategy on climate engineering. As a responsible, large developing country, China would never implement climate engineering without a sound scientific and political basis.

6. Conclusions

Climate engineering hazards significantly environmental risk that places it far beyond the consideration of today's China. However, China should closely monitor and perhaps join the global discussion on governance relating to climate engineering, including participation in current international schemes and potential global governance frameworks that include climate engineering regulations. First, climate engineering, the Plan B to conventional climate change mitigation measures, should be studied and researched from a scientific stand-point. Second, to reduce the public's manipulation by the media, the Chinese government needs to clarify its stance on climate engineering. All relevant clarifications need to be supported by credible natural and social scientific research. Third, Western countries and international societies are actively discussing topics related to the development of climate engineering and its potential global governance structures, which will regulate future studies and research on climate engineering in addition to the potential ethical, political, economic impacts. China should prepare itself for possible future discussions and negotiations on climate engineering.

Since there are large uncertainties in both the natural and social sciences, in relation to climate engineering, China should invest more of its resources into the analysis and research of this topic. If conventional mitigation and adaptation fail to rescue the Earth from future climate disasters, climate engineering would be a final alternative. Yet research cannot wait until that day comes. Furthermore, if climate engineering projects are unexpectedly implemented, perhaps without proper consultation or regulation, people should be aware of the possible consequences and be prepared to possibly mitigate the negative impacts on the environment, economy, and human health.

Only with thorough advanced research can policymakers provide equitable, rational, and reasonable answers to the questions relating to climate engineering. Thus, there are several sub-topics that require further investigation, particularly in social sciences.

The first of the social science sub-topics that needs more supporting research is agriculture, which is the most vulnerable sector, regardless if the impacts were caused by conventional climate change or by climate engineering. Proper evaluations and simulation monitoring should be conducted on potential agricultural disasters resulting from climate engineering. Risks and cost-benefit analyses should be based on simulations that account for the indicators retrieved by metrological and climatic models. Second, extreme climate events, including their possible social economic costs, should be evaluated using implemented climate engineering projects scenarios. Third, in comparison with conventional mitigation and adaptation actions, climate engineering may impact the pathway choices for energy utilization and innovation. Relevant social economic impacts and costs, related to energy development transformation under the circumstances of feasible climate engineering, should be calculated. Fourth, after obtaining certain information on the above issues, policymakers need to construct a decision-making framework based on their ethical, political, and economic principles. Finally, researchers should also provide their expert insight into future global governance structures, given all of the principles and pathways available for sustainable development.

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