Climate Engineering: Changes and Challenges

Masterarbeit

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Introduction:

Motivation and Relevance:

The world population is expected to reach 9,5 billion in 2100.[1] This is associated with an increasing demand for resources. The energy sector has to grow by about 30% within the next 20 years in order to satisfy this demand.[2] The same counts for food production, which will occupy a growing share of the Earth's surface. While it might be technically feasible to service such a large amount of people, there will be a price to pay. The worldwide carbon dioxide emissions are growing faster and faster, with most being produced by the energy and transport sector. Both sectors need to grow in order to sustain the world's population and thereby will the amount of greenhouse gas emissions grow. Between 1990 and 1999 the CO2 emissions have increased at a rate of about 1,3% per year. Between 2000 and 2006 this rate has increased to 3,3%.[3] Although the worldwide amount of emissions decreased by 0,6% in 2019, 39 Gt of carbon dioxide have been emitted. The burning of fossil fuels alone is releases around 25 Gt. Data acquired from ice bores indicate that the current carbon dioxide levels are the highest in the last 650.000 years. These high levels are the main cause of climate change. Next to the worldwide rising temperatures as the main symptom of it, there are other negative consequences such as increasing acidification of the oceans. By the end of this century a global rise by 1-6°C is predicted. The warming of the planet leads to disturbances in the weather system, destruction of ecosystems, extinctions of species and melting of the polar caps. Glaciers in Greenland are as small as never before and the Artic ice shield loses ever-increasing parts. This leads to a rising sea level which will endanger people living near the coastlines worldwide. It is assumed that the polar bear is one of the next species that will be extinct in the wild as its habitat is destroyed.[4] In order to weaken the effects of the climate change the international community of nations has committed itself to reduce the warming to maximally 2°C. This would mean that from 2018, only 1200 Gt more of carbon dioxide more allowed to be emitted.[5] With the current insufficient global mitigation efforts, it is unlikely that this aim will be met.[6] In order to prevent the climate change from making the Earth uninhabitable, CE need to be considered as well. The deliberate modification of parts of the climate system can help to fill the gap between the insufficient mitigation and the rising carbon dioxide levels. Furthermore, some of the assumed methods are able to

[1] Vaughan, Lenton, 2011, p. 750
[2] DFG, 2019, p. 15
[3] Vaughan, Lenton, 2011, p. 746
[4] Crutzen, 2006, p. 211, 214, 216
[5] DFG, 2019, p. 10
[6] Lenton, Vaughan, 2009, p. 5539

counteract the temperature rise within a short period of time so that part of the already happening consequences of climate change might be stopped or at best be reversed.

Research Questions and Structure:

As CE is neither a much-discussed topic in the public debate about the climate change nor is it or its possible advantages known to the general public, this thesis gives an overview over the possible intervention activities next to mitigation they might be usable for in order to combat climate change. As a fast response is beneficial, special attention is paid to those methods that are assumed to deliver timely results, especially the use of sulfate aerosols to reduce the incoming solar radiation. Therefore, the following research questions are answered:

- What are the possible methods with regard to CE?
- How well-advanced is their practical usability?
- What are the barriers in their development and use?

The first chapter of this thesis gives more detailed information about the causes and effects of climate change to further illustrate how severe it is and what the possible outcome of insufficient countermeasures would look like. The following chapter gives background information about the functionalities of the climate system. The most important interlinkages of its components, transport processes within the atmosphere and influences on global weather are described. This information is important in the later chapter about the use of sulfate aerosols to understand how their application can interfere in this system. The third chapter defines CE and gives an overview over its two subsections which are described in more detailed in the following two chapters. First, the general characteristics of CDR are named and afterwards individual advantages and disadvantages of selected methods are outlined. Subsequently, the same is done for RM. Here, special attention is paid to the scattering of radiation method especially with the use of sulfate aerosols. In addition to describing its advantages and disadvantages, possible interferences with the climate system, transport options and deployment patterns within the atmosphere are named. The sixth chapter deals with the responsibility which accrues from an implementation of one or more CE methods. Thereby social, legal, environmental and economic aspects are distinguished. Following this is a chapter regarding the low level of awareness of CE. It is shown that the lack of publicity is a major disadvantage. The discussion chapter criticizes the previous chapters and highlights the most important aspects. The final chapter gives a summary of the entire thesis and names required actions.

As CDR methods are less abstract and more tangible, it might be reasonable to start a public discussion with only these as topics. This might answer some of the mentioned questions and create a better understanding for CE in general. Thereafter, the acceptance for RM methods might be higher.

Conclusion:

CE is a complementation to mitigation efforts. From a long-term perspective mitigation is the less costly, less risky and most efficient solution in combating the climate change. However, as this long-term perspective does not pay sufficiently enough attention to the current problems, CE, and especially RM, need to be considered in the worldwide efforts to handle this problem.

Raising awareness on the topic of willfully modifying the climate is the first step for an implementation of such methods in the future. Society can only properly decide if such an interference is on the behalf of the mankind. Next to technical feasibility there are several factors that need to be considered in the context of CE. A deliberate interference in the climate system affects the life of every individual on the planet in nearly every aspect. Furthermore, it will have severe consequences for the environment. The current level of knowledge about the proposed methods is so low that a practical use is far from being realizable. Nevertheless, an increase in the research efforts for CE in general and the especially for the most promising methods, sulfate aerosols and direct air capture, is necessary within near future. This is a fact that is strengthened by all scientists active in this field of research and current research will enable a future use of these methods. When proposing CE to the public, this is a fact that must be made clear in order to for rejection to be minimized.

When it comes to the different methods for CDR and RM, most of them are too risky given their rather low potential to combat climate change. Sulfate aerosols are the most promising method to obtain fast results with respect to decreasing the temperature. Although there are practical examples in form of volcanic eruptions that prove that they can decrease the global temperature, there are major differences in the distribution patterns between an eruption and a deliberate injection into the atmosphere. Furthermore, there is a difference between the higher amount-shorter time allocation of the sulfate particles from volcanic outbreaks compared to the lower amount-longer time allocation that is proposed for the RM method. Deliberate sulfate injections in the stratosphere have the potential to alter the transportation and weather processes in the atmosphere, possibly having immense negative impacts for the planet. To further evaluate the associated risks and increase the level of knowledge about the exact

interlinkages in the climate system, more and combined research effort is needed. The same applies to direct air capture. Although CDR methods are generally less risky as they do not interfere as intensely with the climate system as RM methods usually do, the knowledge about this method is too little to allow a timely practical use. Additionally, the storage of the captured carbon dioxide is not adequately clarified.

Starting a discussion regarding CE involving the public, scientists of all affected sectors and the politicians is the next reasonable step. Furthermore, research on all aspects of CE should be strengthened, not only on technical feasibility. Currently, research about the possibilities to combat climate change are stagnating, while the effects of climate change are more and more noticeable. There is still time to begin with an effective strategy to manage the climate change and reverse it at some point, but the clock is ticking.