Ethics of Climate Engineering: Chemical Capture of Carbon Dioxide from Air

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Abstract: In the coming decades, scientists will be increasingly confronted with opportunities to pursue research with implications for one or more climate engineering proposals. Now is the time for chemists to critically reflect on the controversial possibility of managing the climate and its ethical implications. The ultimate goal of this case study on ethics and climate engineering is to promote critical reflection and discussion on the ethics of climate engineering research. To fulfill its goal, this paper will investigate four questions: (1) Why should scientists and engineers consider climate engineering research? (2) What is climate engineering? (3) What is the substance of a common ethical objection to climate engineering, the moral hazard objection? (4) How might we begin to address crucial ethical concerns with climate engineering?

Keywords: *Climate engineering, ethics, technological fix, moral hazard, direct air capture, Carbon Engineering.*

1. Introduction

As the deadline for implementing effective international political action to prevent dangerous climate change draws closer, interest in climate engineering is growing. In coming years, opportunities for scientists and engineers to conduct research directly, or indirectly, related to climate engineering will increase. But should scientists and engineers contribute to this research? Chemistry research, for example, stands to make important contributions to climate engineering, but would it be right? While modern chemistry has made enormous positive contributions to humanity, some research has caused much harm, particularly environmental pollution. As a result, professional organizations have established ethical guidelines for research. Would climate engineering research be consistent with commonly stated responsibilities to public safety, welfare, and the environment (AIChE 2015)? Would this re-

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search contribute to "environmental sustainability" and "protect the environment for future generations" (ACS 2016)? These kinds of questions require careful examination when faced with the controversial idea of controlling the climate system.

Climate engineering raises many ethical issues, but certain issues are central. The Royal Society's report on climate engineering observes that moral hazard arguments are "one of the main ethical objections to geoengineering" (Royal Society 2009, p. 39). Moral hazard objections argue that climate engineering research will undermine efforts "in mitigation and/or adaptation because of a premature conviction that climate engineering has provided 'insurance' against climate change" (*ibid.* p. 37). However, the report states that, "the moral hazard argument requires further investigation to establish how important an issue this should be for decision makers" (*ibid.* p. 45). This article will ultimately focus on this important, but confusing, ethical objection to climate engineering research. The moral hazard objection opens the door to other ethical issues that researchers should consider when asking, is climate engineering research the right thing to do? To set the stage for considering this question, this article will explore three related issues: Section one will explore why scientists and engineers should consider climate engineering research. The next section will examine the nature and varieties of climate engineering schemes. The third will analyze the substance of the common moral hazard objection to climate engineering. The article will conclude by identifying principles capable of addressing the deep ethical issues associated with climate engineering research.

1. Why consider climate engineering?

1.1 Climate-intensified disasters: famine, refugees, and war

There is a two-part answer to the question, why scientists and engineers should consider climate-engineering research. The first part points to building evidence that the consequences of climate change could be catastrophic. The second part points to the slow pace of political efforts to prevent this possible catastrophe. The climate crisis is sometimes framed as a transition from the Holocene to the Anthropocene (Rockström & Klum 2015). The Holocene epoch (the past 10,000-plus years) has been exceptionally favorable for humanity. During this short period, the human population exploded from a few million hunter-gatherers to an emerging global technological civilization of over 7.5 billion people. Thousands of years of favorable climatic conditions allowed for the development of agriculture and permanent settlements, which evolved into civilizations. The calm of the Holocene is not the norm for the Earth's 4.5 billion-year history, and we can no longer take this calm for granted (*ibid.*). The impacts of 7.5 billion people on the Earth is ushering in a new epoch, the Anthropocene (Steffen *et al*. 2007). If the planet's climate system moves from the current epoch of predictability to one of volatility, the results could be tragic.

The Anthropocene, the 'human age', ironically threatens to be a tempestuous period, unwelcoming to human civilization. We can already feel the leading edge of these changes in more frequent and powerful tropical storms, longer and more extreme droughts and heat waves, sea-level rise and flooding, and massive wildfires. The American climate activist and writer Bill McKibben remarks that "in almost every corner of the Earth," climate "chaos" is inducing "an endless chain of disasters that will turn civilization into a never-ending emergency response drill" (Mann 2014). There are signs that McKibben's characterization of "climate chaos" is not hyperbole but an emerging reality for many.

In 1980, the United States' National Oceanic and Atmospheric Administration (NOAA) began keeping track of meteorological disasters costing over one billion US dollars. While there are fluctuations from year to year, the trend-line of billion-dollar disasters is clear: the number is on the rise, with 2017 being the most costly year on record. In 2017, hurricanes, floods, and wildfires caused over $300 billion in damage in the United States (Smith 2018). These dollar amounts do not take into account the immeasurable harms of human suffering and loss of life. NOAA identifies climate change as a major factor in increasing the intensity and frequency of all these disasters. The trend of more frequent and severe weather-related disasters is similar in Europe: a 2017 European Commission report warned, that if "not curbed, climate change-related disasters, with heat waves being the greatest concern, could expose some 350 million Europeans to harmful climate extremes every year" (European Commission 2017). The report highlights the need to halt climate change and adapt to its unavoidable consequences.

The countries of North America and Europe are among the largest emitters of greenhouse gases (GHG). These countries have the power to slow climate change and the capacity to adapt to many of its consequences. However, many countries in Africa, and the Southern Hemisphere in general, can do neither of these things. These countries are historically minor emitters of GHG and they lack the governmental, financial, and technological capacities needed for resilience and adaptation. Even under climate change of 2 °C to 3 °C, the countries of Africa will likely experience severe impacts.

In 2016, the United Nations' Environment Programme (UNEP) issued a report that painted a dire picture of Africa's future in the Anthropocene. The report predicts that in coming decades as the climate warms, African countries will increasingly experience more severe and frequent weather-related disasters, which will lead to famine, military conflicts, and political instability. The report warns: "Even with a warming scenario of under 2° C, Africa's undernourished would increase 25-90%. Crop production would be reduced across much of the continent as optimal growing conditions are exceeded. The capacity of African communities to cope will be significantly challenged" (UNEP 2016). If the international community is unsuccessful in reducing GHG emissions, 'business as usual' scenarios foresee an average global temperature rise of 3-4 °C by the end of the century. The consequences for Africa would be truly catastrophic.

The perfect storm bearing down on Africa has serious implications for Europe. Africa's population is predicted to double by 2050 to 2.5 billion. The combination of explosive population growth, climate-intensified disasters, and inadequate adaptive capacity could result in a refugee crisis for Europe. Stefano Torelli writes: "The combination of poverty, dependence on agriculture, environmental degradation, and population growth […] can be expected to translate into increasing forced migration" (Torelli 2017). Torelli warns that Europe is unprepared to deal with the flood of climate refugees. The forced migration of millions of African would further stress an already-stressed Europe, which will be experiencing climate-related disasters like heat waves. Similar problems could be repeated around the globe.

For instance, South Asia is profoundly vulnerable to climate-intensified disasters due to the region's large population and extreme poverty (Bhatiya 2014). Karachi, Pakistan has a population of over 20 million. It is the economic center of a country where nearly 50% of the population lives below the United Nations' poverty rate of less than one US dollar a day (UNDP 2013). Karachi is vulnerable to climate-intensified disasters such as heat waves and flooding (Nazar 2016): in 2015, the city suffered a heat wave that killed over 1,500 people (*ibid.*). Because of the city's lack of infrastructure and lowland geography, it is prone to flooding. These factors, and others, make Karachi, and Pakistan, acutely vulnerable to climate change. Climate change could displace 40 million Pakistanis (*ibid.*). Another country in the region, Bangladesh, is likely to suffer even more than Pakistan. A 2013 report by the World Bank reports that "Bangladesh will be among the most affected countries in South Asia by an expected 2 °C rise in the world's average temperatures in the next decades, with rising sea levels and more extreme heat and more intense cyclones threatening food production, livelihoods, and infrastructure as well as slowing the reduction on poverty" (World Bank 2013). Climate change could displace 20 to 50 million Bangladeshi (Glennon 2017).

Climate change is often characterized as a 'threat multiplier' for military conflict. Competition for increasingly scarce water, food and energy resources could trigger conflicts in this region with several nuclear powers. (Bhatiya 2014). To further complicate the power dynamic of the region, neighboring China is a now an economic and military superpower that could be drawn into a regional conflict (Lone 2015). The United Nations Environment Programme and the European Union, recently labeled climate change a global security threat (UNEP 2018). Further, many military experts see climate change as threat "to international security and the future existence of modern civilization" (Causevic 2017).

This brief discussion points to a few pieces of evidence that climate chaos could lead to social and political chaos. A group of scientists recently published an article that framed the challenges humanity faces in coming decades in terms of two trajectories, Stabilized Earth and Hothouse Earth (Steffen *et al*. 2018). The scientists used systems theory to identify possible tipping points that could push the Earth System in to a new, irreversible state, Hothouse Earth. This analysis serves a dire warning. "[Hothouse Earth] pose severe risks for health, economies, political stability (especially for the most climate vulnerable), and ultimately, the habitability of the planet for humans" (*ibid.*). However, the door is not shut, but "rapidly closing" on the Stabilized Earth pathway (*ibid.*). The Stabilized Earth trajectory will require more "deliberate management of humanity's relationship with the rest of the Earth System" (*ibid.*). The authors "suggest that a deep transformation based on a fundamental reorientation of human values, equity, behavior, institutions, economies, and technologies is required" (*ibid.*). The question is, can these ethical, political, and behavioral transformations happen in time?

The philosopher Christopher Preston observes that something about the climate change problem has the "temptation of procrastination built in" (Preston 2018). In his article, 'The Perfect Moral Storm', Stephen Gardiner identifies several reasons why this unprecedented, global problem contains the temptation of procrastination (Gardiner 2006). Perhaps the foremost reason is that the lack of immediacy creates a lack of urgency. People living today must start taking action now to avert future catastrophe, but the tragic consequences of inaction are temporally and spatially distant. They seem unreal. Another factor, which will be discussed later, is the daunting task of creating international intuitions capable of building cooperation between nations, which is vital to solve this global problem. Finally, there are powerful vested interests in the current energy system that are resistant to change. For these reasons, and others, we are postponing the difficult Stabilized Earth pathway and are drifting toward Hothouse Earth. This situation is leading some to take a more serious look at climate engineering.

1.2 The slow pace of climate change politics and climate engineering

The United Nations initiated its Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro in 1992. After nearly three decades, these efforts have a weak record of reducing GHG emissions. The UNFCCC's two landmark achievements are the 1997 Kyoto Protocol and the 2015 Paris Agreement. The Kyoto Protocol failed to slow rising rates of GHG emissions; the world's economies are no less dependent on fossil fuels today, and GHG emissions continue to rise. The Paris Agreement replaced the Kyoto Protocol and was designed to correct its flaws. In broad outlines, the 175 parties (174 nations plus the European Union) who signed the Paris Agreement committed to collectively reducing GHG emissions with the goal of limiting temperature rise to less than 2° C and strong efforts to limit temperature rise to 1.5° C. Unlike the Kyoto Protocol, the Paris Agreement requires every nation, developed and developing, to submit GHG reduction targets along with a plan called an Intended Nationally Determined Contribution (INDC), to achieve those targets. The agreement also includes the Green Climate Fund, which assists developing countries as they implement adaptation and mitigation plans. The Paris Agreement is a clear advance over the Kyoto Accord. However, until countries develop a sustained track record of fulfilling their commitments, the negotiated INDCs and commitments to the Green Climate Fund are merely good intentions. Paris provides reason for hope, but it is difficult to be too hopeful given the record of past efforts. Increasing doubt about political efforts is leading to a change of attitudes about climate engineering (Boettcher & Schäfer 2017).

Until recently, the last 15-20 years, most climate scientists saw climate engineering as scientifically dubious, ethically suspect, and a dangerous distraction. However, seeing dangerous climate change quickening on the horizon, some scientists and decision-makers began to view climate engineering in a new light. One of those scientists was the eminent, Nobel Prize-winning Dutch atmospheric chemist, Paul Crutzen. In 2006, he published an influential article that broke the taboo on climate engineering. The article asserts that it is time for serious scientific discussion of climate engineering. He writes: "given the grossly disappointing international political response to the required greenhouse gas emissions [...] research on the feasibility and environmental consequences of climate engineering […] should not be tabooed" (Crutzen 2006, p. 214). The article proved to be a watershed for climate engineering, taking it from fringe to mainstream.

In the years before Crutzen's article, only a handful of publications had been devoted to climate engineering. But just one year later in 2007, publications began to surge. A recent article tracks the growth of publications devoted to climate engineering from 1971 to 2013. In 2007, there were 21 publications. In 2008 that number had grown to 73 and by 2013 that number more than doubled to 153 (Oldham *et al*. 2014). Another significant indicator of climate engineering's increasing respectability is its inclusion for the first time in the Intergovernmental Panel on Climate Change (IPCC)'s 5th Assessment Report in 2014 (IPCC 2014). It seems from this evidence that many scientists are accepting the idea of a need for climate engineering research.

By way of summary, the above begins to answer the question, why scientists and engineers should consider climate engineering research. Evidence is accumulating that climate chaos will lead to social, political, and environmental chaos; and it appears that political efforts to avert climate chaos might fall short. If the climate system continues down the Hothouse Earth pathway, the consequences for human civilization could be catastrophic. Further, it seems increasingly unlikely that political efforts alone will be able to put civilization on the Stabilized Earth pathway. It seems right to *consider* climate-engineering research.

However, a technological 'cure' should not be worse than the 'disease'. How can scientists be sure that climate engineering research will do more good than harm? As noted in the introduction, one of the most common ethical concerns is that climate engineering creates a moral hazard. For climate engineering research to be ethically responsible, this concern must be understood and addressed. A first step toward understanding the moral hazard objection is to investigate the implication of climate engineering as a technological fix.

2. What Is Climate Engineering?

2.1 Climate engineering is a technological fix

Climate engineering is often characterized as a technological fix. While the idea of engineering the climate is unprecedented, climate engineering schemes are the product of the commonly applied technological fix strategy. The idea of a technological fix is simple: it is a problem-solving strategy that reframes intractable sociopolitical problems as engineering puzzles that emit technical solutions (Weinberg 1967). Possible solutions to multifarious and capricious sociopolitical problems are more easily identified when these problems are reframed in the clear and predictable terms of physics, chemistry, and engineering.

Modern societies often see technological progress as the quickest and surest path toward economic and social progress; there is a propensity to believe that technological solutions are easier and less painful than behavioral, social, or political solutions (Volti 2014). Governments and industries spend tens of billions each year on research in agriculture, medicine, energy, transportation, the environment, and more, to develop technologies to address problems with sociopolitical roots. It should come as no surprise that climate engineering research would eventually enter into high-level climate change discussions. However, technological fixes are instinctively criticized for being superficial solutions that fail to address the roots of problems. Nonetheless, this problem-solving strategy has several benefits. It offers decision makers additional options for addressing difficult problems. Technological fixes can buy time until problems can be dealt with on a deeper level (*ibid*.). Finally, a technological fix may simply be the best available option all things considered. This might be particularly true for problems with firm deadlines.

Climate change would seem to be a perfect candidate for the technological fix strategy. It is an intractable sociopolitical problem that can be readily reframed as an engineering puzzle. Once the problem is reframed in the terms of physics and chemistry, it presents scientists and engineers with a clear task: develop technologies that will stabilize the Earth's solar energy balance. There are two general approaches to this task: solar radiation management (SRM) and carbon dioxide removal (CDR). SRM research focuses on techniques that increase the Earth's albedo (reflective capacity). CDR research, as the name indicates, focuses on techniques that remove CO_2 from the atmosphere.

2.2 Solar radiation management (SRM)

Some SRM proposals are expensive and futuristic, like installing an array of mirrors in orbit around the Earth. Other plans are inexpensive and less high-tech, like using long hoses suspended by high-altitude balloons to spray sulfate particles into the stratosphere. Crutzen's watershed article focused on this approach. Large volcanic eruptions are known to cool the planet in the same way: in 1991 the cataclysmic eruption of Mount Pinatubo in the Philippines blasted approximately 17 megatons of sulfur dioxide into the stratosphere (Self *et al*. 1996). Microscopic sulfuric acid aerosols formed and circled the planet, reflecting incoming solar radiation back into space. Some estimates suggest that the Mount Pinatubo eruption decreased the global average temperature by 0.4 Celsius for two years (*ibid*.). Stratospheric sulfur injection is an attractive technological fix because it is a quick and cost-effective way to lower the Earth's average global temperature (Moreno-Cruz & Keith 2013). However, the full range of consequences would be difficult or impossible to anticipate prior to full-scale implementation, and the stakes would be extremely high. While the effects of an SRM on global average temperature might be predictable, its effects on regional weather patterns are much more difficult to foresee. Stratospheric sulfur injections and other SRM plans do nothing to remove GHGs from the atmosphere, which would continue to increase (*ibid*.). SRM only masks the warming effects of GHGs. While the following discussions will focus on CDR techniques, the ethical analysis applies also to SRM. I will use the SRM example in the final section to illustrate ideas for developing ethical guidelines for responsible climate engineering research.

2.3 Carbon dioxide removal (CDR)

There is a wide array of possible CDR techniques. To illustrate their diversity, I will mention three: ocean fertilization, enhanced weathering, and bioenergy with carbon capture and storage (BECCS).

Large areas of the oceans do not have adequate concentrations of iron to support phytoplankton blooms. Ocean fertilization schemes take advantage of this fact by proposing to spread powdered iron across vast areas of the oceans to produce huge phytoplankton blooms, which would capture CO_2 during photosynthesis. Once the organisms expire, the captured carbon would sink to the bottom of the ocean where it would be trapped and stored by water pressure (Powell 2008).

Enhanced weathering schemes seek to harness global biogeochemical cycles. The idea is to accelerate chemical weathering processes that capture atmospheric carbon and store it in soils and the ocean. The technique mines calcium- and magnesium-bearing silicate rocks and crushes it to maximize the reactive surface area. The rock debris is then added to soils where it chemically breaks down to release base cations and generate bicarbonate from atmospheric CO_2. The bicarbonate is stored in the soils or it eventually flows into the oceans, leading to carbonate precipitation on the seafloor. Enhanced weathering projects would likely need to be located in the warm and wet tropics where chemical weathering's reaction rates are high enough to be effective (Beerling 2017).

A final example is industry-scale bioenergy with carbon capture and storage (BECCS). BECCS schemes propose to transform energy sectors to burning carbon-neutral biomass. The biomass fuel captures CO_2 from the atmosphere during photosynthesis. Rather than releasing the CO_2 produced during combustion as a pollutant, the gas is captured and stored in underground geologic formations.

CDR techniques can be implemented at scales that would not qualify as climate engineering. Ocean fertilization, enhanced weathering, and BECCS projects would have to be immense to qualify as climate engineering. At these scales, they would very likely have significant social, political, and environmental impacts, which would raise ethical concerns. For example, the quantities of powdered iron fertilizer and the huge phytoplankton blooms could have serious unintended consequences for the world's oceans (Powell 2008). Similarly, mining and crushing rock at climate engineering scales would surely have serious social and environmental impacts. Moreover, it would be very difficult to create the international, democratic institutions needed to equitably distribute the burdens from these impacts (Lawford-Smith & Currie 2017). This could lead to environmental justice concerns; that is, concerns that vulnerable populations would bear a disproportionate burden of any social and environmental impacts.

With this overview in mind, it will be helpful to use a specific case to focus the examination of the moral hazard concerns. The case involves direct air capture (DAC) of carbon with chemicals and it will focus on a company, Carbon Engineering. Carbon Engineering recently reported a major chemical engineering breakthrough in DAC that could have far-reaching implications for climate engineering.

2.4 The case of Carbon Engineering

In 2018, a team of scientists and engineers from the Canadian company Carbon Engineering published the results of a promising technique for directly capturing CO_2 from the air with chemicals. The DAC technique can be used to convert the captured carbon into synthetic fuels or to store it in geologic formations. (Keith *et al.* 2018). David Keith, a Harvard University physicist and leading expert on climate engineering, is Carbon Engineering's co-founder. Significantly, the company's primary financial backer is Bill Gates, who was the co-founder of Microsoft and is one the world's wealthiest people. Carbon Engineering appears to be well on the way to solving two of the major obstacles associated with BECCS schemes: competition for land and high costs. Perhaps an insurmountable obstacle to the wide-scale application of biofuels is that they compete with food production for arable land. Since Carbon Engineering's technique uses industrial chemical processes it does not compete with agriculture. Just as significant, their technique greatly lowers the costs of DAC.

DAC of carbon and storage (DACCS) seemed to many a tantalizing technological fix for climate change, but it proved to be far too expensive. Prior to the publication of Carbon Engineering's 2018 results, the definitive study of the costs of industrial-scale DAC estimated the price to be $1000 US dollars per metric ton of CO_2 (House *et al.* 2011). To put this number in perspective, it would cost approximately $1.2 trillion to capture the CO_2

emitted by coal-fired power plants in the United States during 2017, approximately 1.2 billion metric tons (US Energy Information Administration 2018). A central problem DAC must overcome is the 'net carbon problem' (*ibid.*). The concentration of CO_2 in ambient air is extremely small, approximately 400 parts per million (Burrows 2018). Consequently, large industrial machines must move massive amounts of air through the process to capture enough CO_2 for the technique to work. These industrial machines, and other parts of the operation, require much energy. Energy, of course costs money, and depending on the source of energy, the operation will add more or less CO_2 to the atmosphere. An accurate assessment of this technique for climate engineering would require a full accounting of the CO_2 added to the atmosphere during the operation and for the full lifecycle of the plant. These numbers will not be available until experiments are run at larger scales for longer times.

Carbon Engineering estimates that their technique would lower costs from the 2011 study from $1000 to the range of $94 to $232 per metric ton of CO_2 (Keith *et al.* 2018). They were able to accomplish this by developing a new chemical process and by repurposing existing industrial technologies to run it. Their approach uses arrays of large fans to move massive amounts of air over a chemical solution to capture CO_2. They describe the chemistry as involving two connected loops: "The first loop captures CO_2 from the atmosphere using an aqueous solution with ionic concentrations of roughly 1.0 M OH^-, 0.5 M CO_3^{2-}, and 2.0 M K^+. In the second loop, CO_3^{2-} is precipitated by reaction with Ca^{2+} to form $CaCO_3$ while the Ca^{2+} is replenished by dissolution of $Ca(OH)_2$. The $CaCO_3$ is calcined to liberate CO_2 producing CaO, which is hydrated or 'slaked' to produce $Ca(OH)_2$" (*ibid.*). They produce synthetic fuel by a conventional process commonly used in the oil industry, which reacts CO_2 with H_2 to produce fuel. Carbon Engineering is currently seeking funding to test their chemical processes and technologies at larger scales.

It is important to note that the company is not currently pursuing plans to capture carbon and store it, for example, in geologic formations. Their research focuses on producing 'carbon-neutral' synthetic fuels, which is only possible if the electricity used to drive the process is generated from a non-carbon producing source, such as a hydroelectric plant. Further, it should also be noted that the current process uses some natural gas, which researchers hope to replace with electricity and make the process carbon neutral. That said, David Keith notes that the company could adapt their technique for producing 'carbon neutral' fuels to be used as a negative emissions technology. However, Keith remarks that, "[carbon storage] wouldn't give Carbon Engineering any product to sell, and there are no buyers stepping up to front the effort, for now" (Meyer 2018). For Climate Engineering's technique to realize any potential for climate engineering, a market for removing carbon from the atmosphere and 'permanently' storing it would have to exist. However, this might be an instance where a proof of concept technology could help create a market for the service it could someday provide. Once negative emissions technologies are seen as a possible way to make vast fortunes, while also providing a vital social benefit, it is easy to imagine that the political will to create a market for CCS will somehow emerge – especially with powerful advocates like Bill Gates leading the way.

Carbon Engineering is pioneering a potentially multibillion-dollar industry that might someday serve as a technological fix for the climate crisis. One journalist notes that "[Carbon Engineering] could […] make Harvard superstar physicist David Keith, Microsoft co-founder Bill Gates, and oil sands magnate Norman Murray Edwards [another powerful financial backer] more money than they could ever dream of" (Vidal 2018). If Carbon Engineering continues to attract wealthy and politically influential backers like Bill Gates and Norman Murray Edwards, the creation of a CCS industry could transform the landscape of climate change politics. This could be a mixed blessing: the promise alone of cost-effective CCS could create a moral hazard, which, as will be explained, could lead to an ethical dilemma for scientists considering CCS research.

3. What is the Substance of the Moral Hazard Objection?

3.1 The temptation of procrastination

As mentioned, moral hazard arguments are "one of the main ethical objections to geoengineering" (Royal Society 2009, p. 39). One problem with these objections is the notion of a moral hazard is not a traditional ethical concept, but originated in the insurance industry. It describes a perplexing problem for insurers: when workers are provided with hazard insurance there is a corresponding increase in risky behaviors (*ibid.*, p. 37). Those who raise moral hazard objections to climate engineering worry that it will be seen as insurance against climate change, which will lead to greater risk-taking behaviors. Stated differently, the possibility of a technological fix will tempt people to delay or avoid taking the difficult steps to put civilization on a Stabilized Pathway, and destine humanity instead to the harsh realities of Hothouse Earth.

This is a sensible argument, but there are difficulties with using the moral hazard objection as an ethical argument. The moral hazard phenomenon identifies a correlation between insurance and risk-taking behaviors, but these behaviors by themselves may not necessarily be unethical, or unreasonable. Moral hazard objections to climate engineering are better seen as premises in a larger argument that includes, as will be seen in section 3.3, premises grounded in ethical concepts such as justice and fairness. The argument would also need to include premises about the "temptation of procrastination" (Preston 2018). The Carbon Engineering case can serve to illustrate this later point.

Ken Caldeira, a leading expert on climate engineering, points to the allure of an easy technological fix, commenting that, "If [Carbon Engineering's] costs are real, it is an important result […]. This opens up the possibility that we could stabilize the climate for affordable amounts of money without changing the entire energy system or changing everyone's behavior" (Meyer 2018). More generally, climate scientists Anderson and Peters observe that, "The allure […] of negative-emission technologies stems from their promise of much-reduced political and economic challenges today, compensated by anticipated technological advances tomorrow" (Anderson & Peters 2016). It is easy to imagine that the promise of a negative emissions technological fix could become a temptation to procrastinate on the daunting task of transforming the whole energy system and changing entrenched energy consumption habits. Further, business leaders and politicians who are heavily vested in the fossil fuel industry could use promising CDR or SRM technologies as temptation for further delays in transitioning from fossil fuels to alternative energy systems. The substance of the moral hazard objection is that promising breakthroughs with potential for climate engineering intensify the temptation to procrastinate, which will lead to delays on the hard sociopolitical tasks climate change requires. Further, it is far from certain that negative emissions technologies, like Carbon Engineering's, will fulfill their promise at scale. Climate engineering is a risky insurance policy for a high-risk scenario.

However, an underlying assumption of the moral hazard-procrastination argument is that the right thing to do is to trust sociopolitical fixes over technological fixes. However, are sociopolitical efforts trustworthy? Given the brief discussion in Section 1.2, should we continue to trust that sociopolitical solutions can be implemented in time? To examine this question, let us look closer at the nature of the political task.

3.2 Climate politics and the dilemma of climate engineering

The political task of achieving an effective international climate change agreement is unprecedented in human history. In the first few decades of the 21st century, nations must transition from the 20th century's ethos of conflict, defined by two world wars, the Cold War, and the War on Terror, to an ethos of trust and cooperation. At least within the sphere of climate change negotiations, this shift requires nations to stop viewing each other as suspicious competitors long enough to cooperate on solving this common problem, but with differentiated responsibilities.

Climate change politics got off to promising start at the 1992 Rio Earth Summit, where 154 nations cooperated in the creation the United Nations' Framework Convention on Climate Change (UNFCCC). The UNFCCC set the right tone with commitments to equity and justice, which it extended to future generations. It states that the Conference of Parties agrees to protect "the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities" (United Nations 1992, p. 4). However, it has proven difficult for countries to move from acting on self-interest to *consistently* acting on these ethical commitments. The problem of inconsistency is glaring for the United States, the world's second-largest emitter of CO_2 and largest per capita emitter.

The United States is divided politically on climate change. This is reflected in the striking swings in its behaviors toward UNFCCC agreements. For example, in 2015, under President Obama's leadership, the United States helped lead the way toward the landmark Paris Agreement. One year later, after Donald Trump's shocking victory in the presidential election, he promptly took actions to start withdrawing the United States from the Agreement. In one year, the United States went from a vital leader to a major hindrance to the success of the breakthrough agreement. This political divide in the United States renders this key nation an unreliable partner, which threatens to undermine trust in the entire effort.

The United States is singled out here because of the remarkable reversal with the improbable election of Donald Trump, but there are trust issues with other nations. China is the world's largest CO_2-emitting nation and its cooperation is essential for a successful agreement. Several news sources reported in 2015 that based on data from independent monitoring agencies, China had been underreporting its coal consumption by fifteen percent (Buckley 2015). This reinforces suspicions that the Chinese government manipulates carbon emission data for economic and political purposes (Liu 2015, p. 14). It is unlikely that China's behavior is unique and it no doubt added to an atmosphere of mistrust and suspicion about the negotiations and ultimate agreement.

The Paris Agreement does not include effective enforcement mechanisms to discourage countries for reneging or cheating on their commitments. Strong enforcement mechanisms can be added to future agreements. However, until these are added, critics argue that the UNFCCC's efforts will fail. For example, during the Paris conference, the eminent climate scientist James Hansen was quoted in the press as saying the Agreement is a "fraud [...]. It is just worthless words. There is no action, just promises" (Milman 2015). Hansen's words may be too harsh, but the high level of trust between untrustworthy parties required by the Paris Agreement is reason to be skeptical.

The capriciousness and inscrutability of real-world, international politics vanishes when the problem is reframed as a technological fix. But the lure of an easy climate-engineering fix creates a temptation to despair of achieving more long-term sociopolitical change. However, to be realistic is not to give up hope. The benefits of a successful international political process are too great to succumb to despair. Climate engineering is no substitute for transformative social and political change. Also, effective policies to reduce CO_2 emissions would be far safer than climate engineering. There are no guarantees that a climate engineering scheme would be successful at scale or that it would not create more problems than it solves. Fortunately, there is still time for consistent and honest leadership to emerge from key nations. It is also possible for future agreements to include more aggressive, legally binding national commitments to reduce CO_2 emissions and strong enforcement mechanisms. The appropriate attitude might be a hopeful realism, which would require a sustained commitment to sociopolitical efforts while pursuing climate-engineering research. Unfortunately, the moral hazard-procrastination argument points to a dilemma for this middle approach.

Scientists and engineers considering the ethics of climate engineering research must face a dilemma. On the one hand, if we vigorously pursue climate-engineering research we risk undermining political efforts by creating temptations for further procrastination. And, climate engineering is risky and is not a substitute for political efforts (Meyer 2018). On the other hand, if we do not vigorously pursue climate-engineering research and shaky political efforts fail, vetted and tested climate-engineering techniques may not be available and nations could implement climate engineering in desperation. Either choice requires taking risks that could lead to serious consequences. Fortunately, it might be possible to address this dilemma with ethical guidelines for responsible climate engineering research that serve as a foundation for strong, inclusive, international governance.

3.3 Moral hazard, climate engineering, and justice

In an article criticizing an overreliance in the potential of negative emissions technologies, climate scientists Kevin Anderson and Glen Peters relate the moral hazard concern to issues of justice and fairness (Anderson & Peters 2016). They argue that gambling on negative emissions technologies leads to an unjust distribution of risks. If these technologies are pursued but fail to work at scale, the wealthy and resilient communities that are researching and developing them will not be the ones to suffer the most harm. Rather, "communities that are geographically and financially vulnerable to a rapidly changing climate" and future generations (*ibid.*) will face the greatest harms of disasters, famines, and wars. The unfair distribution of risks of climate engineering can be applied to all SRM and CDR proposals.

The moral weight of this argument comes from extending the unjust distribution of risks historically built into the climate problem to the distribution of risks with climate engineering. On the one hand, high-emitting countries owe their prosperity to the combustion of fossil fuels. These countries can do much to address the problem by reducing their CO_2 emissions, and they have greater adaptive capacity because of their prosperity. On the other, historically low-CO_2-emitting countries, who have contributed little to the problem, can do little to address it, and lack the resources to adapt to it. This unfair distribution of responsibilities and risks is magnified with climate engineering. Vulnerable communities are not responsible for research and development of climate engineering technologies and they are at greatest risk if research undermines mitigation efforts or the technology fails.

It is especially unjust to gamble the fate of vulnerable people, and future generations, on risky technological fixes when sociopolitical solutions are still available. Anderson and Peters note that "there are huge opportunities for near-term, rapid, and deep reductions today at little to modest costs, such as improving energy efficiency, encouraging low-carbon behaviors, and continued deployment of renewable energy technologies" (*ibid.*). However, they qualify their argument. Negative emission technologies can "reasonably be the subject of research, development, and potentially deployment" (*ibid.*). But this research must be done with the conviction that if it will not be successful at scale, "failing to do otherwise are a moral hazard par excellence" (*ibid.*).

The above discussion relates the moral hazard-procrastination concerns to justice and fairness concerns. In doing this, it points out that issues of justice and fairness should be paramount in developing ethical guidelines for responsible climate engineering research. Climate engineering research should not intensify and enlarge injustices that are inherent in the climate change problem.

4. Conclusions: How Do We Address These Concerns?

In an article discussing the 2010 report of the United States' Presidential Council on Bioethical Issues, the council's chair, Amy Gutmann, states that the principle of justice and fairness should be broadly applied to powerful emerging technologies (Gutmann 2012). This would certainly include climate engineering. Gutmann writes that the "principle of justice and fairness relates to the distribution of benefits and burdens" across societies and generations (*ibid.*). She elaborates, "a commitment to justice and fairness is a commitment to ensuring that individuals and groups share in the benefits of new technologies and that the unavoidable burdens of technological advances do not fall disproportionately on any particular individual or group" (*ibid.*). A good beginning for efforts to apply the principle of justice and fairness to climate engineering research would start with the following: (1) inclusive and impartial research on the impacts of climate engineering proposals, (2) inclusive international participation in research, and (3) transparency and openness in research funding.

First, the principle of justice and fairness would require scientific knowledge of the possible social and environmental consequences of various climate engineering proposals at multiple levels. Clearly, without detailed knowledge of the possible consequences of a particular climate-engineering proposal, it is impossible to consider a just distribution of risk, harms, and benefits. The majority of research on the most frequently discussed SRM proposals focuses on how the climate system would respond to stratospheric sulfate injections, while the environmental and social impacts at various levels are under-researched and uncertain (Trisos *et al*. 2018). There is a critical need for collaborative research between natural and social scientists to understand the effects on agriculture, community health, and regional and local ecosystems (*ibid.*). For example, some computer simulations of stratospheric sulfate injections indicate that the reflective sulfate aerosols would indeed cool the planet, but with the unintended consequence of reducing the amount of precipitation from the summer monsoons in Asia and Africa (Robock *et al*. 2008). This would have serious consequences for agriculture and billions of people's food supply. It is clear, then, that the principle of justice and fairness would require adequate funding of research aimed at answering the many questions on impacts and whom they would affect in order to prevent injustices.

Second, the principle of justice and fairness would require inclusive international participation in research. Again, it is unjust for resilient, wealthy countries to put vulnerable communities in danger with risky climate engineering schemes when they are not consulted and do not participate in the research. This issue is raised in a recent article in the journal *Nature*, whose title asserts "Developing Countries Must Lead on Solar Geoengineering Research" (Rahman *et al*. 2018). The international team of authors argues that for climate engineering research to avoid unjust governance, underrepresented, developing nations need to take the lead. Currently, North American and European scientists are overrepresented in climate research. This leads to a danger of biases (conscious or unconscious) towards these countries' interests. This situation could ultimately lead to an unfair distribution of the harms, risks, and benefits of a climate engineering project. Rahman and his co-authors argue that since "developing countries have most to gain or lose" from SRM research, these countries need greater representation (*ibid.*). They summarize the situation: "Solar geoengineering is fraught with risks and can never be an alternative to mitigation [...]. It is right, politically and morally, for the global South to have a central role in solar geoengineering research, discussion, and evaluation" (*ibid.*). In an effort to involve developing countries in SRM deliberations, Rahman and his co-authors are engaged in the Solar Radiation Management Governance Initiative (SRMGI). One of SRMGI's objectives is to produce a special Intergovernmental Panel on Climate Change report on the risks and benefits of SRM (*ibid*.). Their ultimate goal is to create "a coordinated global research initiative [...] to promote collaborative science on this controversial issue" (*ibid.*). By fostering broadly inclusive international representation in research, the SRMGI is an example of the kinds of initiatives needed to implement the principle of justice and fairness.

Third, and finally, the principle of justice would require transparency and openness in research. Transparency and openness in research raise numerous issues, not all of which I can highlight here. But one of the most important is the question of allowing privately funded research and intellectual property rights for novel climate engineering technologies. The profit motive and intellectual property rights are primary sources of funding and incentives for research. Should private funding, international intellectual property rights, and the profit motive be allowed for SRM and CDR? Both publicly and privately funded research come with advantages and disadvantages. On the one hand, publicly funded research could build greater confidence in its focus on public goods, but public financial resources are often limited and centralized and bureaucratic decision-making can limit innovation. On the other hand, privately funded research offers access to additional sources of funding, and with decentralized decision-making can promote greater innovation. However, it risks creating vested interests that could corrupt democratic decision-making. Scientists, investors, or companies who are awarded intellectual property rights for a specific climate engineering technology, for instance DAC technologies, could make a fortune if it is widely adopted. Intellectual property rights would create incentives for people and corporations to promote the adoption of their technology, even if alternative technologies would better serve public interests. This could create a moral hazard, as there would be a financial motive to encourage the adoption of a climate-engineering technology, which could in turn create a temptation to procrastinate on sociopolitical efforts.

This ethical concern is likely more of an issue with CDR technologies than SRM. As was seen with Carbon Engineering, some technologies operate at scales that are too small to be considered climate engineering, but they could be scaled into a CDR project to cool the planet. Private enterprises with the potential to generate fortunes for investors, like Climate Engineering, raise a difficult problem. It could ultimately serve the global, common good to use the private corporations, the profit motive, and the intellectual property rights system to encourage as much innovation as possible. However, there is the danger that the promise of financial success could shift the political landscape, leading to further procrastination and risking injustices. This type of situation will be a major challenge for responsible climate engineering research.

By way of summary, this article started with these questions: Should scientists and engineers contribute to climate engineering research? Is it the right thing to do now? Would climate engineering research be consistent with responsibilities to protect public welfare and safety, contribute to environmental sustainability, and protect the environment for future generations (AIChE 2015, ACS 2016)? The answers provided in this article show climate engineering research should be considered. However, because of the unprecedented nature of this technology, it needs clear ethical guidelines and strong governances to provide researchers with the confidence that they are doing the right thing. The moral hazard objection, the temptation of procrastination, and the inherent injustices built into climate change problem lead to serious concerns with this research. The above discussion points to principles of justice and fairness as the right starting point for developing ethical guidelines for responsible climate engineering research. The principle of justice would at least require inclusive and impartial research on impacts and techniques, and transparency and openness on funding sources as starting points for effective governance.

Recommended Readings

Preston (2013) provides a clear and concise overview of the types of climate engineering and the main ethical issues currently being discussed. Keith

(2013) develops a detailed argument why societies *must* consider deploying climate engineering. Hulme (2015) is a counterpoint to Keith, he develops arguments why *must not* consider a climate engineering fix.

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