A PROPOSAL FOR CLIMATE ENGINEERING GOVERANCE IN PURSUIT OF ETHICAL AND EFFECTIVE RESEARCH

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Ten years. That is how long many activists and scientists say the world has before the impending climate catastrophe hits (Wagner & Samaras, 2019, para. 1). Ten years before the Earth's temperature reaches levels far above preindustrial levels, causing irreversible damage. Only ten years to do something to stop this tragedy from happening. Already across the United States, environmental disasters and extreme weather events occur at higher frequency and severity (Branch & Plumer, 2020, para. 2). These cataclysms and more unmentioned across the globe test the threshold of human adaptability, on top of endangering existing plant and animal populations. The Intergovernmental Panel on Climate Change (IPCC) met in 2015 to create the Paris Agreement. Chief among the promises was a resolution that member countries would do what they could to limit the temperature increase to 1.5 degrees Celsius. To achieve this goal, greenhouse gas (GHG) emissions would have to drop by about 50% by 2030 and reach net zero by approximately 2050 (Wagner & Samaras, 2019, para. 2).

Carbon dioxide (CO_2) is the most prevalent GHG globally and the most discussed in research and policy to stop climate change. According the United States Environmental Protection Agency (n.d.), 81% of United States GHG emissions in 2018 were CO_2 (p. 1). As such, traditional methods of climate change mitigation generally primarily call for CO_2 emission reductions. Examples of mitigation efforts are better fuel efficiency in cars, carpooling, and switching to renewable energy sources, among many others. This route, dubbed emission reduction, is not without its downsides. On top of the challenges that come from changing norms on a societal or industrial level, cars are on the road for an average of twelve years, and power plants from the 1950s are still generating electricity (Wagner & Samaras, 2019, para. 7). Therefore, most changes implemented now through traditional mitigation methods could take decades to create results, and the world might not have that long. In fact, the IPCC's Integrated Assessment Model's most recent model showed that out of 900 scenarios, only 76 pathways achieved the 2 degrees Celsius goal, and most of these pathways entailed a drastic method called climate engineering (Hester & Gerrard, 2018, para. 7).

Climate engineering, commonly known as geoengineering, is the intentional manipulation of Earth's climate in order to fight the impacts of global warming. Within climate engineering, there are two categories (1) solar radiation management (SRM), also known as albedo modification or solar geoengineering, and (2) carbon dioxide removal (CDR). Figure 1 illustrates the role in the fight against climate change that climate engineering addresses in relation to mitigation and adaption. Unlike mitigation and adaption that either attempt to stop climate change at the start or adjust to the changed climate after the fact, respectively, climate engineering intervenes in the middle of the process, which allows it to have large and immediate

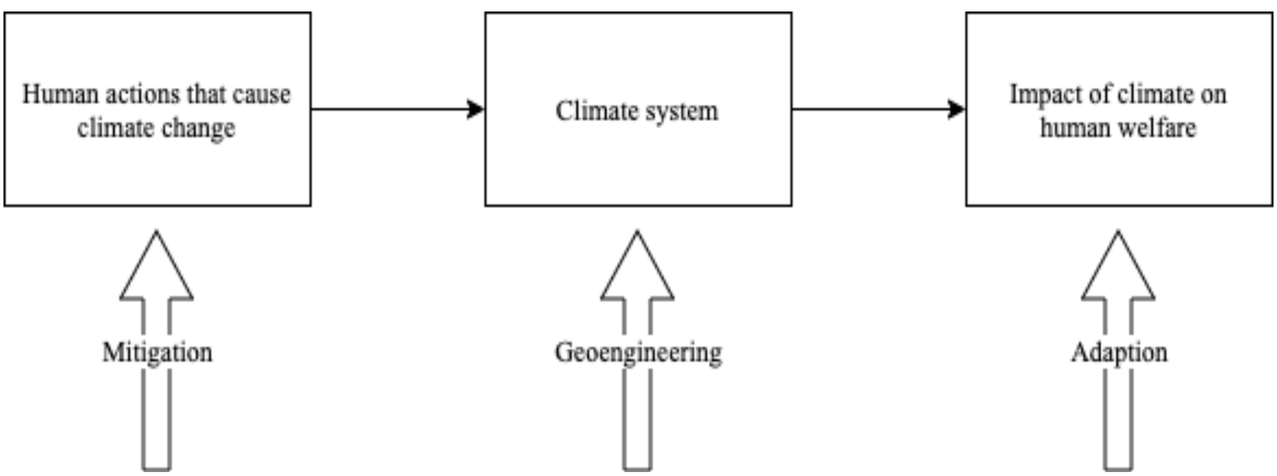

Figure 1: Three-part scheme of the climate problem: The horizontal arrows in the top row show the casual chain in this version of the anthropogenic climate problem. The vertical arrow and the bottom row define the modes of intervention (Keith, 2000).

effects. Climate engineering techniques are highly controversial and have been for decades. Many experts fear that, when global leaders at last recognize the danger at hand, they will have no choice but to implement engineering projects whose risks have not been thoroughly researched and could bring worse consequences than the problem they fix (Anderson, 2017, p. 415). In fact, calling climate change and global warming emergencies or crises has been criticized as these framings could be abused to rationalize setting aside democratic decision making for unilateral, radical attempts at fixes (Gupta et al., 2020, p. 10).

Currently, climate engineering, especially solar radiation management, is considered exceedingly risky, so risky that some believe even its research is unethical (Gertner, 2017, para. 7). Admittedly, most of climate engineering has only been explored in small field experiments; therefore, its methods are underdeveloped, and its risks and effectiveness are both inadequately understood (Reynolds & Parson, 2020, p. 324). Only carbon dioxide removal is currently implemented outside a lab. This status quo should change as the abilities and limitation of the technology need to be understood before the technology must be implemented in political desperation (Blackstock, 2012, para. 7). Moving forward, regulation and oversight is necessary as the few climate engineering experiments in the works are funded by philanthropists without public accountability or checks and balances (Anderson, 2017, p. 415).

Both types of climate engineering will be explored in this author's capstone project. The technical portion offers a CDR design proposal for a cement manufacturing process that adds full oxy-fuel combustion and accelerated carbonation curing to make the process a means of carbon capture and storage. The sociotechnical thesis discusses how to promote effective and safe research and innovation through international and national regulation of climate engineering methods, focusing on SRM techniques, in the fight against global warming using the lens of Actor-Network Theory, a conceptual STS framework developed by Bruno Latour, Michel Callon, and John Law ("Actor Network Theory," 2004, p. 1). These two topics are tightly coupled.

BACKGROUND ON CLIMATE ENGINEERING

Climate engineering and geoengineering are not strictly synonyms. The distinction is minor and new. The term geoengineering was coined in the 1970's by Cesare Marchetti, and at first was the only term in use (Keith, 2000, p. 247). The phrase climate engineering did not enter the lexicon until the 21st century. Climate engineering describes a specific form of geoengineering that is large-scale and aimed at fighting climate change whereas geoengineering technically describes any manipulation of the climate at any scale. For example, in 2008 Chinese soldiers fired over one thousand rockets containing chemicals at clouds over Beijing to stop an impending rain shower during the Olympics (Specter, 2012, para. 19). This illustration is an example of geoengineering that is not climate engineering due to its lack of climate change fighting intentions and local scale. This paper will emphasize the distinction between these two terms, but readers should note that common vernacular uses the terms interchangeably.

Geoengineering has been around for a less than 200 years, and only in the most recent decades has it been considered a realistic technology as opposed to a strictly theoretical concept. The earliest known examples of theoretical geoengineering date to the 1800s when James Pollard Espy claimed that by lighting large fires rain can be artificially induced and Svante Arrhenius linked rising carbon dioxide levels in the atmosphere from burning fossil fuels to rising global temperatures which, in his mind, could allow humans to create better climates and hold off the coming ice age (McCormick, 2013, para. 2; Specter, 2012, para. 19). It was not until after World War II when the Soviet Union and the United States heavily researched cloud seeding and other ways of triggering precipitation as part of the Cold War that climate engineering began to transition from radical ideas to practical proof of concepts. In 1965, United States President Lyndon Johnson was given a novel report, titled "Restoring the Quality of Our Environment," by scientific advisors which discussed climate change intervention tactics that would be described as climate engineering today (Biello, 2010, para. 1). This report is widely considered to be the first documentation promoting climate engineering techniques and research.

There are two terms that will be referenced repetitively in this research paper that are critical to understanding the climate problem and the issue of regulating climate engineering. They are defined in the following subsections.

The Earth's Albedo

At its most simple, the Earth's albedo is the quantity in a range of 0-1 that describes how much of the Sun's energy is reflected away from the Earth's surface. An albedo of 0 means that no energy is reflected back, while an albedo of 1 means that it is a perfect reflector. The Earth has an average albedo of 0.31 ("Albedo and climate," n.d., para. 4). Solar radiation management (SRM) alters the albedo through techniques such as cirrus cloud thinning, space mirrors, stratospheric aerosol dispersal, marine cloud brightening, among several more, which is why SRM is also referred to albedo modification. The intention is to have less energy absorbed on the Earth's surface or have more energy reflected away.

The Global Commons

The global commons are the four international domains that are beyond any one nation's sovereignty and contain resources to be shared across the world. The four global commons are the oceans, the atmosphere, outer space, and the Antarctic. The global commons are critical in understanding the lack of regulation surrounding climate engineering. The following three technologies pose particularly interesting hurdles as they require deployment from oceans or the atmosphere, requiring brand new to international governance as they cannot be fit under the current models of international sovereignty and security: ocean iron fertilization, sulfur aerosol dispersal, and marine-based cloud brightening (Chalecki and Ferrari, 2018, p. 85-86).

CONTROVERSIES AND IMPACTS

As seen in Figure 1 on page 2, climate engineering tackles a part of the climate problem that mitigation and adaption are unable to affect directly. The Intergovernmental Panel on Climate Change (IPCC) has conceded that solar geoengineering could singlehandedly limit global warming to below 1.5 degrees Celsius (Reynolds & Parson, 2020, p. 324). However, critics claim that reliance, or even any extent of use, of SRM will dissuade many from exerting effort to lower GHG emissions, committing to sustainable practices, and other more acceptable and established means of climate change mitigation (Robock et al., 2008, p. 17). There is some validity in this claim, which is why global governance must be implemented. Once regulated, climate engineering will be well positioned to be practiced concurrently with mitigation and adaption, not to replace these methods by buying time for the other methods to be implemented and take effect themselves (Reynolds & Parson, 2020, p. 324; Anderson, 2017, p. 415). Another climate engineering controversy applies only to SRM. Once SRM is deployed, it must be continuously sustained else the termination effect, a rapid reversal and increase in temperature, will occur (Reynolds & Parson, 2020, p. 325). If emissions that cause global warming and climate change are not dealt with, SRM should not be stopped until they are, less the termination effect put the world in a worse situation that it is currently. Another controversy arises due to the lack of research and challenges posed by field testing is the impacts of climate engineering are uncertain.

Direct Environmental Impacts

The direct environmental impacts of climate engineering are the most understood. Volcano eruptions mirror what would be expected of sulfur aerosol dispersal, a promising SRM technique. Stratospheric ozone depletion and acid rain from sulfates, changes in the amount and pattern of precipitation, and increased growth rates of forests have all been observed after volcano eruptions (Liu & Chen, 2015, p. 198). Ocean fertilization, a tactic that includes dumping nutrients into the sea, may lead to eutrophication and oxygen depletion (Liu & Chen, 2015, p. 198).

Indirect Environmental Impacts

There is a wide range of theories attempting to predict what the indirect environmental effects of climate engineering will be. Climate engineering may lower the global mean temperature but cause fluctuations in temperature and precipitation at local levels which could disrupt greatly local agriculture and established ecosystems (Liu & Chen, 2015, p. 198). These side effects may not be distributed equally but differ regionally, endangering local biodiversity. Because SRM does not reduce anthropogenic CO_2, ocean acidification will continue. Sulfur aerosol dispersal will likely change the color of the sky to a milky gray (McKibben, 2021, para. 2). There are likely many more side effects that need to be considered before implementation of climate engineering.

Impacts on Climate Mitigation Politics and Policies

Beyond the environmental impacts that climate engineering poses, there are societal impacts whose influence cannot be overlooked. Gunderson et al. (2018) states that SRM upholds powerful economic interests and protects “an inherently ecologically harmful social formation” (p. 1) He states due to the aforementioned capacity of SRM to be implemented without mitigation or adaption techniques. Being able to just pause global warming, protects the interests of those who primarily cause climate change by permitting their dangerous behavior to continue. Branch and Plumer (2020) point out that investors are more likely to invest based on where the crisis is most obvious and who are the effected parties; more urgency with funding research would occur if Washington D. C. was hit, not Oregon (para. 20). This discrimination unfairly puts different populations at distinct risks based on political and economic interests out of their control.

Solar radiation modification (SRM) is extremely cheap, which brings both positive and negative consequences. Harvard professor David Keith, an expert in the climate engineering field, argues that for only $1 billion each year, any party with access to high altitude aircraft, such as balloons or planes, can implement SRM (Gertner, 2017, para. 2). There are numerous private citizens who could shoulder this bill, including Bill Gates who recently invented in SRM (Cohen, 2021, para. 1). The price tag is low enough that many governments, not just economic world leaders or otherwise dominant nations, can choose to enact SRM in self-interest, possibly devastating other countries. As previously mentioned, some of the indirect environmental impacts, such as changes in precipitation and temperature, will fluctuate throughout the world. Countries could research and carefully implement SRM to ensure that their country benefitted while their neighbors shouldered the disadvantageous side effects. Future, large-scale deployment of SRM without “competent, prudent, and legitimate international control could trigger international destabilization or conflict” (Reynolds & Parson, 2020, p. 325).

A REVIEW OF EXISITING TECHNOLOGIES

Climate engineering technologies, especially SRM, face countless hurdles. As SRM is almost an entirely theoretical concept, many proposals for SRM technology have been offered, each with different risks and costs. Getting field trials off the ground is an enormous feat due to the scrutiny and novelty. For example, a field trial was canceled because of lack of rules on how to proceed (Anderson, 2017, p. 415). Two SRM experiments are notable for the progress they made.

Stratospheric Controlled Perturbation Experiment

Out of Harvard's Keutsch Group comes the Stratospheric Controlled Perturbation Experiment (SCoPEx), a scientific experiment trying to increase understanding of stratospheric aerosols in regards to SRM. SCoPEx is positioned to be the first SRM experiment to actually be applied beyond just theory. Their plan is to use a high-altitude balloon to lift the equipment needed for dispersal into the atmosphere. The equipment on the balloon will also be capable of measuring changes in perturbed air mass such as changes in aerosol density, atmospheric chemistry, and light scattering (*SCoPEx: Stratospheric controlled perturbation experiment*, n.d.). The team is based in the United States; however, they are hoping to launch a test run of the equipment in Sweden in Summer 2021.This kind of international cooperation will be standard in geoengineering field tests and implementation.

Stratospheric Particle Injection for Climate Engineering

The Stratospheric Particle Injection for Climate Engineering (SPICE) experiment consisted of three groups: one at Bristol University, one at Cambridge, and one at Oxford (Specter, 2012, para. 11). The groups were in charge of deciding which particles to use to achieve maximum desired impact with minimal side effects, deciding the best dispersal system, and determining the effects produced on the climate, respectively. In Fall 2011, the team tried to conduct a test of the dispersal system, but over fifty organizations signed a petition against the experiment out of fear that it would demotivate politicians from making tough decisions on greenhouse gas emission reduction (Specter, 2012, para. 15). Then, in May 2012, another SPICE field trial was cancelled over a patenting problem that arose from fears that corporate ownership was taking precedence over global public interest (Blackstock, 2012, para. 3).

CURRENT REGULATION IN PLACE

Currently, there exists no regulation internationally, or in the United States, that directly address climate engineering. Lack of regulation denies the technology the critical understanding of who is to control deployment and bear the risks of liability for damages (Hester & Gerrard, 2018, para. 5). This absence of oversight also denies the stakeholders the opportunity to voice concerns (Hester & Gerrard, 2018, para. 5). In 2019, the United Nations tried to create the first global governance regulation to greenlight investigatory research into climate engineering, but the United States and Saudi Arabia blocked the efforts with other parties joining the dissent after (Watts, 2019, para. 5). In this section, various currently implemented regulation will be discussed from three different scopes: international affairs, United States affairs, and wartime affairs.

International Regulation

The international regulation that will be discussed falls into three main categories: (1) protecting the global commons, (2) protecting the environment, and (3) protecting human rights. In many cases these categories overlap. Solar radiation management cannot be implemented within a single nation's sovereignty for that reason international law and policy is critical, and its direct and indirect effects will possibly affect biodiversity and quality of life. The following sections cover various conventions, protocols, and other forms of injunctions that relate peripherally to climate engineering in chronological order. This list is not exhaustive.

1967 Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies and its Liability Convention.

The Outer Space Treaty is a collection of multilateral agreements that provide regulation over the global common of outer space (Reynolds, 2019a, p. 128). The Convention on International Liability for Damage Caused by Space Objects, along with the Outer Space Treaty, dictates the rules of liability for harm from space activities. It clearly states that the party or parties that "[launches], procures the launching, or provides the launching site has absolute liability" (Reynolds, 2019a, p. 128). This provision includes accidents and planned operations, and the victim does not need to demonstrate fault (Reynolds, 2019a, p. 128-129).

1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and the London Protocol. The London Convention, as it is commonly referred, protects all maritime waters from marine pollution from dumping. This includes but is not limited to the global common entity. The 1996 London Protocol replaced the London Convention and uses stronger and more obligatory language (Reynolds, 2019a, p. 123). In addition to preventing pollution, the London Protocol commits its parties to the scientific research of maritime pollution, which could include climate engineering research, as forms such as ocean iron fertilization may constitute pollution. Of note, there is a stipulation that "parties may not transfer, directly or indirectly, damage or likelihood of damage from one part of the environment to another or transform one type of pollution into another" (Reynolds, 2019a, p. 123-124). This is significant for climate engineering as some preliminary research suggests such transfers will be unavoidable (Liu & Chen, 2015, p. 198). In accordance with the two agreements, climate engineering that involve maritime water would have to be permitted (Reynolds, 2019a, p. 124). In 2013, the parties to the London Protocol approved an amendment that is not in effect yet that would govern marine climate engineering (Reynolds, 2019a, p. 124). Included in this amendment are a list of conditions to be met for marine climate engineering to be approved, including but not limited to absence of direct financial gain, being subject to peer review, and making data publicly available (Reynolds, 2019a, p.126). It also highly encourages parties to gain consent from all possibly impacted parties (Reynolds, 2019a, p. 125).

1979 Convention on Long-Range Transboundary Air Pollution. The Convention on Long-Range Transboundary Air Pollution (CLRTAP) is a framework convention with operationalizing protocols (Reynolds, 2019a, p. 72). As is the case with other framework conventions, CLRTAP is weakly-worded and does not strictly obligate any action (Reynolds, 2019a, p. 72). It is a regional agreement developed to deal with acid rain caused by the transboundary movement of pollutants Gerrard and Hester, 2018, p. 72) Its definition for air pollution is similar to other atmospheric treaties. CLRTAP may outlaw the use of sulfur aerosols for stratospheric aerosol dispersal due it being considered air pollution (Chalecki & Ferrari, 2018, p.89). However, the wording implies the harmful effects must be of a specific threshold and have actually already occurred for CLRTAP's definition of air pollution to apply. Sulfur generally is the aerosol discussed for stratospheric aerosol dispersal due to the inspiration of volcano eruptions that disperse sulfur aerosols, which is not considered a form of pollution. Greenhouse gases and global warming may also be defined as air pollution by CLRTAP, and, given that there is a commitment in the agreement to research and develop technology that reduces air pollution, CLRTAP may give the green light and obligation to climate engineering research (Gerrard & Hester, 2018, p. 73). This conflicting relation with climate engineering will be seen throughout the discussion of international regulation.

1982 UN Convention of the Law of the Sea. The UN Convention of the Law of the Seas (UNCLOS) covers activities in, on, or above the oceans. UNCLOS establishes a party's rights, duties, and other commitments while engaged in maritime activities, including those that relate to the protection of the maritime environment and the execution of maritime research (Reynolds, 2019a, p.114). Article 1 defines pollution of the marine environment; this article does not restrict the point of origin, so it can be from land, atmosphere, or anywhere else (Reynolds, 2019a, p. 115). Article 1 also defines what dumping entails, which is relevant for cirrus cloud thinning and stratospheric aerosol dispersal (Reynolds, 2019a, p. 121). Some articles within UNCLOS commit the parties to strengthening maritime technology and promoting research which could imply that parties are obligated to develop climate engineering technology and research (Reynolds, 2019a, p. 121). Like the London Protocol, UNCLOS prohibits the transfer of damages or pollution from one part of the ocean to another, a provision that climate engineering will likely infringe (Reynolds, 2019a, p. 117). Article 140 states that any activity engaged in the high seas must be for the universal benefit of the world not just the state or states engaged in the activity (Chalecki & Ferrari, 2018, p.89). This naturally leads to the conclusion that any party wishing to implement marine-based climate engineering must first prove that the actions to be taken benefit all of mankind. There are unclear implications regarding non-state entities' responsibilities and liabilities under UNCLOS, which may complicate implementation of climate engineering by non-state actors (Reynolds, 2019a, p. 120).

1985 Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol. Before global warming became the prominent environmental problem, the destruction of stratospheric ozone by anthropogenic substances was the foremost issue (Reynolds, 2019a, p. 96). These agreements are relevant for climate engineering as stratospheric aerosol dispersal may lead to ozone depletion or slow down its current recovery (Reynolds, 2019a, p. 96). The Vienna Convention is a framework convention with limited commitments (Reynolds, 2019a, p. 96). The Montreal Protocol further develops the Vienna Convention, most notably by phasing out specific ozone-depleting substances. The implications of the Vienna Convention and the Montreal Protocol are two-fold. Firstly, specific climate engineering tactics, such as stratospheric aerosol dispersal with sulfurous compounds, may be completely banned. More research and policy interpretation need to be conducted to decide the outcome. It possible that there will be a balancing out effect between ozone depletion and the blocking of ultraviolet radiation (Gerrard and Hester, 2018, p. 71). Additionally, sulfate aerosols are, for example, emitted by industrial practices, such as coal combustion, at rates ten times that needed for stratospheric aerosol dispersal, and yet, these emissions are not controlled. The net effect of cirrus cloud thinning is also unclear due to its ability to block the rise of water vapor but also its natural ozone depleting nature (Gerrard and Hester, 2018, p. 71). Secondly, the Montreal Protocol is a great example of international regulation that worked. Future regulation over climate engineering should mirror its practical methods. How so will be discussed in the conclusion of this paper.

1992 Convention on Biological Diversity. This convention addresses actions that endanger ecological biodiversity. The Convention on Biodiversity (CDB) is a far-reaching, weakly-worded framework treaty; however, its robust international support and expansive scope have led to its use in wide range of issues and contexts (Reynolds, 2019a, p. 129). The secretariat released a report regarding climate engineering, specifically concerning solar radiation management (SRM), that spoke to SRM's capacity to mitigate the effects of global warming on biodiversity but lamented the uncertain new risks for biodiversity that SRM may create (Reynolds, 2019a, p. 129). In 2010, the tenth conference of the parties ruled on climate engineering and called for its implementation to be indefinitely postponed until research into its impact on biodiversity could be completed (Chalecki & Ferrari, 2018, p. 89). In 2012, the parties reaffirmed the statements from 2010 and added language noting "the ongoing lack of science-based, global, transparent, and effective control and regulatory mechanisms" (Reynolds, 2019a, p. 130). The statements of the CBD are non-binding as the conference of parties do not have the authority to make new international law (Reynolds, 2019a, p. 131). The findings are still important, regardless of their legal standing, as they are the only example of negotiated consensus among parties that represent most of the world (Reynolds, 2019a, p. 131).

1992 UN Framework Convention on Climate Change. The UN Framework Convention on Climate Change (UNFCCC) is the preeminent international legal instrument addressing global warming and climate change (Gerrard & Hester, 2018, p. 64-65). As a framework, it lacks binding obligations; however, it is supplemented by other multilateral agreements and protocols, such as the Kyoto Protocol of 1997 and the 2015 Paris Agreement. The UNFCC is anthropocentrically and economically focused, which guides many of regulation and objectives (Reynolds, 2019a., p. 93). The tenets of the UNFCCC include intergenerational equity, sustainable development, among others (Gerrard & Hester, 2018, p. 66). The UNFCCC directly relates to the carbon dioxide removal side of climate engineering, as carbon dioxide is a major greenhouse gas that accumulates in the atmosphere. The UNFCCC does not directly address solar radiation management as those techniques do not involve directly greenhouse gases. The structure of the UNFCCC, including but not limited to regular party meetings, reporting standards, and a secretariat, is well-equipped for adaption by future climate engineering governance. Additionally, the UNFCCC could easily serve as a preliminary governing body for climate engineering until a more permanent solution is established.

United States Regulation

The United States is a world leader, both politically and as an emitter of greenhouse gases; yet, it lacks any policies that directly address climate engineering and, for that matter, any particularly robust climate change policies. In fact, it is not even party to many of the just discussed international agreements. An important distinction for the United States that does not apply in the same way to other countries is the fact that there are differences in policy federally and among the states. Many of the soon-to-be discussed policies have state counterparts. This complicates climate engineering research in several ways; for example, it requires researchers to go through multiple permitting processes with different requirements and forces researchers to consider transboundary politics in the same way as internationally. Nevertheless, the implementation of the any climate engineering tactics within United States borders will likely be subjected to the following federal regulations.

1963 Clean Air Act. The Clean Air Act works to control "air pollutants from stationary and mobile sources and from new and existing ones" with its objective being the public health and welfare of the United States (Reynolds, 2019a, p. 140). The structure of the policy consists of a federal framework executed by the Environmental Protection Agency that obligates states to develop specific regulations to meet the standards (Reynolds, 2019a, p. 140). It targets specifically acid rain and visibility; however, President Obama used his power of executive authority to implement regulation of greenhouse gases under the Act. The implications of the Clear Air Act on stratospheric aerosol dispersal highly depend on further research findings. Of the specifically regulated pollutants, stratospheric aerosol dispersal will likely include two: sulfates and particulate matter (Reynolds, 2019a, p. 140). The Supreme Court ruled in *Massachusetts v. Environmental Protection Agency* that the altitude of introduction of pollutants does not matter, be it the troposphere or stratosphere; however, as the aim of the Clean Air Act is the protection of public health and welfare the harm, or lack thereof, mitigates the pollution (Reynolds, 2019a, p. 140). This caveat benefits solar radiation management and stratospheric aerosol dispersal as field tests at low altitudes will be small enough not to cause harm while large-scale field tests and implementation will be at a high enough altitude to likely not cause harm to public health, negating the restriction from the Clean Air Act.

1970 National Environmental Policy Act. The National Environmental Policy Act (NEPA) applies to any "major federal actions significantly affecting the quality of the human environment" (Gerrard & Hester, 2018, p. 155). Its geographic jurisdiction includes the United States territories and the global commons (Reynolds, 2019a, p. 143). Its broad scope makes it central to United States environmental governance (Reynolds, 2019a, p. 142). Climate engineering and the United States federal government are necessarily intertwined for several reasons. The federal government is the largest sponsor of research in the United States so funding will likely come at least in part from them, they would likely be required to oversee any large-scale implementation or field testing of climate engineering due to the potential fallout environmentally and politically, and traditionally across the world nations have claimed climate modification fall under state jurisdiction (Gerrard & Hester, 2018, p. 155; Reynolds, 2019a, p. 143). While NEPA procedure entails many expenses and steps, the greatest obstacle for climate engineering due to NEPA would be the public scrutiny often generated by the process and the possibility that opponents would use NEPA to legally or politically shut down research efforts (Gerrard & Hester, 2018, p. 155). Public discourse and a platform for opposition actually provides a major service to climate engineering research, despite the trouble, as will be discussed in the conclusion.

1972 Weather Modification Reporting Act. The Weather Modification Reporting Act (WMRA) differs from NEPA in scope as it applies to private or public and federal or nonfederal activities (Gerrard & Hester, 2018, p. 160). WMRA defines weather modification as "any activity performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere" (Gerrard & Hester, 2018, p. 160). It mandates any weather modification activity to be reported in advance to the National Oceanic and Atmospheric Administration, and, upon conclusion, save trade secrets, all information and data be made public (Gerrard & Hester, 2018, p. 160). In the context of climate engineering, WMRA will affect solar radiation management and some forms of carbon dioxide removal as these technologies will fit the definition of weather modification either by direct intent or by their side effects (Gerrard & Hester, 2018, p. 160). The primary asset of WMRA is its inclusion of both publicly and privately funded research and its extensive record keeping system. Climate change regulation both internationally and nationally should follow suit.

1973 Endangered Species Act. The Endangered Species Act (ESA) regulates activities that could harm protected species or their habitats (Reynolds, 2019a, p. 143). Any activity that falls under this jurisdiction must report to either the National Marine Fisheries Service for marine species or to the Fish and Wildlife Service for land and freshwater species (Reynolds, 2019a, p. 143). The ESA can be enforced via federal action or citizen lawsuits (Reynolds, 2019a, p. 144). The ESA is relevant for climate engineering consideration because it will be a regulatory hurdle for large-scale, outdoor undertakings (Reynolds, 2019a, p. 144). The ability for citizen lawsuits to occur would give opponents another opportunity to impede climate engineering research, although their claim would have to prove direct causation, which could be difficult in most cases (Reynolds, 2019a, p. 144). Climate engineering also has the potential to rehabilitate endangered species and their habitats, or at least protect them. If this is proven, it might obligate formal inclusion of climate engineering technology in federal conservation efforts as the ESA commits the United States and its representatives to proactively aid the endangered species (Reynolds, 2019a, p. 144).

2017 Geoengineering Research Evaluation Act. This important national bill is the very first policy introduced in any country directly addressing climate engineering, namely solar radiation management (Reynolds, 2019a, p. 148). Democratic Representatives Jerry NcNerney of California and Eddie Bernie Johnson of Texas crafted the measure with the goal of two reports from the United States National Academies (Reynolds, 2019a, p. 148). The first report would propose a federal solar radiation management research agenda, and the second would recommend governance mechanisms for solar radiation management research to maximize the advantages and minimize the risks (Reynolds, 2019a, p. 148). Upon completion of the reports, the Office of Science and Technology Policy in the White House would be called upon to issue an implementation plan for the reports' findings (Reynolds, 2019a, p. 148). The now-defunct bill was not implemented due to no vote occurring on it (Reynolds, 2019a, p. 148). The United States National Academies still are working on the reports (Reynolds, 2019a, p. 148).

War Regulation

There are two facets to understand the importance of war regulation in the scope of climate engineering. First, climate change can be considered a national threat in the same way that a normal party can be considered a threat. Therefore, fighting climate change can be considered a war. The second facet is that the climate change technologies have the potential to "disrupt the global physical status quo…with implications as serious as those in wartime" (Chalecki & Ferrari, 2018, p. 89). Wartime laws in general exist to protect the environment and to protect civilian populations. It is crucial that during the development and research of climate engineering technologies that the same level of precaution is taken since the impact can be analogous. Two relevant war regulations are the 1976 Convention on the Prohibition of Militant or Any Other Hostile Use of Environmental Modification Techniques and the 1977 Geneva Protocol I.

The 1976 Convention on the Prohibition of Militant or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) prohibits the use of military or hostile force to modify the environment in a manner that is long lasting, widespread, or severe. The exact phrasing of ENMOD leaves room for interpretation whether or not it applies to climate engineering, as the intention is neither malicious nor strictly war-related. Chalecki and Ferrari (2018) elaborate on the legal limbo by questioning whether military involvement, such as using military high-altitude aircraft or artillery, make ENMOD apply to climate engineering. while ENMOD refers to months (Chalecki & Ferrari, 2018). The Geneva Protocol I has similar language to ENMOD; however, the time scale for long-lasting or long-term for Protocol I refers to decades

The Geneva Protocol I, or simply Protocol I, aims to protect the victims of international conflict. As aforenoted, Protocol I designated the severe, widespread, or long-lasting destruction of the environment as a war crime. Other specific protections given in Protocol I are over "objects necessary for the survival of civilian populations," such as food and water resources, and built environment works that contain dangerous forces, such as dams and power plants (Chalecki & Ferrari, 2018, p.90-91). The rationale for these regulations is that the health of the environment and civilian population that depends on it should not be compromised during war when "states are granted the greatest legal and operational leeway in national security operations" (Chalecki & Ferrari, 2018, p.91). If such protections are afforded during wartime, it would follow that the rights should also be protected during peacetime and should apply to climate engineering.

ACTOR NETWORK THEORY AND CLIMATE ENGINEERING

Actor-Network Theory (ANT) was proposed in the 1980s and is used to investigate the relationships surrounding a technological advancement. The network is composed of a heterogeneous incorporation of textual, conceptual, social, and technical actors ("Actor Network Theory," 2004). The actors can be human and non-human artefacts that have the capacity to act on other actors and or be acted upon themselves ("Actor Network Theory," 2004). In this case of climate engineering, ANT will be used to investigate how national and international governance agencies play a critical role in the safe development and implementation of climate engineering techniques. The wider actor network of climate engineering, specifically solar radiation modification (SRM), consists of scientists, investors, regulators, politicians, protestors, and state and non-state bodies. State bodies can be categorized into different actor entities including but limited to major carbon-emitting nations, developing countries, and island nations, each of which interact with climate engineering uniquely. SRM policy, as opposed to the technology itself, also matters highly to the energy and agriculture industries and the public (Blackstock, 2012, para. 5).

Climate engineering has to power to affect many different global entities, human and not. Figure 2 depicts the directional relationship and influence of geoengineering on various actors. This figure highlights the four main entities discussed in this research paper and shows how they in turn affect further entities. These actors influence human, animal, and plant populations globally via multiple contexts, including social, political, and economical avenues. It is important to recognize that climate engineering implementation and research will both have distinct regional and global effects. Of note, the United States could be taken to be any industrial, developed country or geographic region and the United Nations could be expanded to include non-United Nations states. This research paper does not consider non-state parties; however, their impact and potential in the climate engineering network are recognized by the author but omitted as beyond the scope of this paper.

Figure 2: Climate Engineering Network: Map of the greater network of geoengineering (Cooper, 2021).

The actor network can be simplified to understand the core problem currently present, which is the lack of regulatory agencies. While Figure 2 demonstrates the expansive, despite scoped, network of impact and influence of climate engineering, Figure 3 below shows the proposed actor network for the continued and improved research of solar radiation management (SRM) and other climate engineering endeavors. Currently, research is being funded by universities and other investors without direct regulatory oversight besides common ethics and non-legally binding guidelines. The fundamental issue arises once climate engineering research moves from theoretical to field tests and patenting, as has been shown by existing research efforts. Earlier sections discussed current international and United States regulation that serve as a mysterious minefield rather than comprehensive regulation. Too much uncertainty exists with regulation, which prevents proper communication to either the investors or the researchers. Figure 3 shows that all parties need to be in mutual, clear communication with the others in order for SRM to be successful. The green arrows denote the new relationships that need to be built. The orange arrows show the relationships that already exist. Once the three entities are in

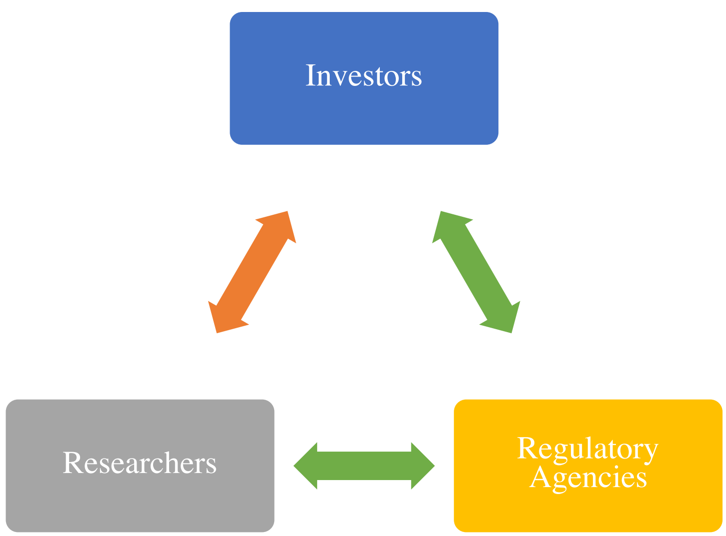

Figure 3: Proposed actor network: The actor network for expedited research of SRM. The three parties that need to communicate effectively for successful research. (Cooper, 2020).

harmony, research will be able to progress, and climate engineering as a whole will be better understood, leading to improved regulation.

A PROPOSAL FOR FUTURE GOVERNANCE

Climate engineering is a powerful technology, quite literally world-changing. Such awesome power must be better understood and regulated. Figure 1 on page 2 can be interpreted as a depiction of the climate change network that climate engineering fundamentally disrupts. Climate engineering can enter the system of the climate problem and completely unaided stop it. As discussed, this unilateral approach to climate change is not a realistic outlook of what climate engineering implementation will look like. However, regulation needs to approach climate engineering for as formidable as it is. It deserves its own recurring convention, international multilateral agreement, and special regulatory system. Climate engineering must be governed on the international stage as climate change is by nature an international issue that heeds no borders and affects all persons. Furthermore, solar radiation management is characteristically transboundary and will likely take place in the global commons, so national governance alone will not suffice.

It is necessary for the eventual success of climate engineering to have regulation set so that researchers know how to proceed and so that the global public feels safe, the global ecosystems and biodiversity are protected, and mitigation efforts are still promoted. These objectives can be accomplished by international agreement and goal setting. The goals need to be exact and descriptive like in the reviewed protocols so that there is no doubt for the researchers, investors, or any other party. The guidelines should be specific and tailored for each technology's foreseeable risks and benefits. They should also distinguish between research and small-scale field testing versus larger deployment. Definitions should be made clear. It would be good to build off the Oxford Principles, which are (i) geoengineering to be regulated as a public good, (ii) public participation in geoengineering decision-making, (iii) disclosure of geoengineering research and open publication of results, (iv) independent assessment of impacts, and (v) governance before deployment (Reynolds, 2019b, p. 11). With these principles at the core of policy, regulation will be sure to proceed cautiously and ethically.

Aspects of the regulation can be inspired by existing regulation. Like the Montreal Protocol and the United Nations Framework on Climate Change Convention, among other agreements and policy, climate engineering regulation should have a standing secretariat and dedicated institutions, regular party meetings, a robust compliance mechanism, and procedures for amending and updating the policy (Gerrard & Hester, 2018, p. 70; Reynolds, 2019a, p. 96). As is the case with the Convention on Long-Range Transboundary Air Pollution there should be a noncompliance procedure that includes a review by an implementation committee (Gerrard & Hester, 2018, p. 74). Having these international parties and practices established will ensure that regulation is kept up to date and that only the most effective and safe climate engineering technology is pursued and implemented. They will also allow for detailed tracking of research progress and public accountability. A transparent permitting system should also be employed wherein researchers must prove the merit of field testing or implementation and establish a reasonable understanding of possible side effects and liability.

National policy also matters greatly for the application of climate engineering technology. National oversight can pay closer attention to ongoing research and more quickly respond to changes in knowledge regarding climate engineering than can an international body. The establishment of national regulation can also occur much more swiftly. The national entity can keep track of continuing research and report it back to the international stage via avenues established in the international agreement. National governmental organizations could also assist in the permitting of research. National entities are also more readily capable of financing climate engineering research, especially while the international body is set up. Overall, the role national regulatory actors like the United States can play is important in the network of climate engineering. They will ultimately be the parties tasked to execute and to abide the international regulation.

By and large, the steps necessary are clear. Climate engineering must be further researched to ascertain its benefits, side effects, and overall potential. It cannot be written off while at this level of understanding by the scientific community nor should the general public's fears control the narrative. While there is a possibility that climate engineering, primarily solar radiation management, will be linked to greater costs and risks than benefits, it would be a disservice to all of mankind to cease all research before it really began. Before climate engineering research can proceed, however, regulation at both an international and national level must be implemented as previously suggested. These precautions will ensure that safe, ethical research gets conducted free of capitalistic self-interest and for the benefit of all mankind and the environment.

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