PUBLIC PARTICIPATION IN SCIENCE AND TECHNOLOGY: A PROPOSAL FOR GLOBAL DELIBERATION ON STRATOSPHERIC AEROSOL INJECTION (SAI)

by
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ABSTRACT

PUBLIC PARTICIPATION IN SCIENCE AND TECHNOLOGY: A PROPOSAL FOR GLOBAL DELIBERATION ON STRATOSPHERIC AEROSOL INJECTION (SAI)

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Keywords: Climate Change, Climate Geoengineering, Stratospheric Aerosol Injection (SAI), Science and Values, Democratization of Science, Well-Ordered Science, Deliberative Democracy, Deliberative Mini-Publics

Stratospheric Aerosol Injection (SAI) is a speculative climate geoengineering technology. If developed, SAI will work by spraying reflective aerosols in the stratosphere with an aim to cool the Earth to counteract anthropogenic climate change. Extant research suggests that SAI can possibly be an effective tool in decreasing temperatures rapidly and at a global scale. However, current scientific understanding of SAI is very limited. There are many uncertainties and risks around the potential benefits and harms of SAI. Despite these uncertainties and risks, certain actors from economics, politics, and science may push for the development and deployment of SAI. According to democratic principles, people should be able to participate in decisions that would impact their lives in important ways. Therefore, SAI-related decisions should be open to public participation. Future decisions on the development, experimentation, and implementation of SAI will depend upon earlier decisions about scientific research on SAI. Thus, public participation in SAI should start early on, comprising all stages of scientific activity. This thesis challenges the value-free ideal of science which sees science as a self-governing domain purified from value influences. It argues that value-laden decisions are inevitable in all stages of scientific activity and that social values should inform these decisions through public participation. Building upon Philip Kitcher's theory of well-ordered science and the extant deliberative mini-public designs, this thesis proposes the establishment of a Global Citizens' Assembly which would allow for informed, deliberative, globally representative, comprehensive, and legitimate public participation in SAI.

ÖZET

BİLİM VE TEKNOLOJİYE HALKIN KATILIMI: STRATOSFERİK AEROSOL ENJEKSİYONU (SAE) ÜZERİNE KÜRESEL BİR MÜZAKERE ÖNERİSİ

ELİF İNCİ ÜNAL

SİYASET BİLİMİ YÜKSEK LİSANS TEZİ, TEMMUZ 2021

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Anahtar Kelimeler: İklim Değişikliği, İklim Jeomühendisliği, Stratosferik Aerosol Enjeksiyonu (SAE), Bilim ve Değerler, Bilimin Demokratikleşmesi, İyi Düzenlenmiş Bilim, Müzakereci Demokrasi, Müzakereci Küçük Toplumlar

Stratosferik Aerosol Enjeksiyonu (SAE), spekülatif bir iklim jeomühendisliği teknolojisidir. Geliştirildiği takdirde, SAI, antropojenik iklim değişikliğine karşı koymak için Dünya'yı soğutmak amacıyla stratosfere yansıtıcı aerosoller püskürterek çalışacaktır. Mevcut araştırmalar, SAE'nin sıcaklıkları hızla ve küresel ölçekte düşürmede muhtemelen etkili bir araç olabileceğine işaret etmektedir. Ancak, SAE'nin mevcut bilimsel anlayışı çok sınırlıdır. SAE'nin potansiyel faydaları ve zararları konusunda birçok belirsizlik ve risk bulunmaktadır. Bu belirsizliklere ve risklere rağmen, ekonomi, siyaset ve bilim alanlarından bazı aktörler, SAE'nin geliştirilmesi ve kullanılması için baskı yapabilir. Demokratik ilkelere göre, insanlar hayatlarını önemli şekillerde etkileyecek kararlara katılabilmelidir. Bu nedenle SAE ile ilgili kararlar halkın katılımına açık olmalıdır. SAE'nin geliştirilmesi, denenmesi ve uygulanmasına ilişkin gelecekteki kararlar, SAE hakkındaki bilimsel araştırmalarla ilgili daha önceki kararlara bağlı olacaktır. Bu nedenle, SAE'ye halkın katılımı, bilimsel faaliyetin tüm aşamalarını içerecek şekilde erkenden başlamalıdır. Bu tez, bilimi değer etkilerinden arındırılmış kendi kendini yöneten bir alan olarak gören değerlerden bağımsız bilim idealini sorgulamaktadır. Bilimsel faaliyetin tüm aşamalarında değer yüklü kararların kaçınılmaz olduğunu ve toplumsal değerlerin bu kararları halkın katılımı yoluyla etkilemesi gerektiğini savunmaktadır. Philip Kitcher'ın iyi düzenlenmiş bilim kuramı ve mevcut müzakereci küçük toplum tasarılarına dayanarak halkın SAE'ye bilgili, müzakereci, küresel düzeyde temsili, kapsamlı ve meşru katılımını sağlayacak bir Küresel Yurttaş Meclisi'nin kurulmasını önermektedir.

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1. INTRODUCTION

Year 2025. Climate change is racing towards catastrophic levels at full speed. A horrific heatwave hits India, killing 20 million people in a single week. Entire towns are wiped out, people are "cooked" in lakes where they escaped to beat the heat. This traumatizing event galvanizes political action against climate change globally, with hopes to avert mass extinction in the next 30 years. An eco-terrorist group who call themselves the Children of Kali begins the War for the Earth, assassinating politicians and CEOs, sabotaging coal plants, crashing business jets, sinking container ships, and infecting cattle to collapse the beef industry. A new UN subsidiary body is established under the Paris Agreement, which comes to be known as the Ministry of the Future. It is charged with "advocat[ing] for the world's future generations of citizens, whose rights, as defined in the Universal Declaration of Human Rights, are as valid as our own", and "defending all living creatures present and future who cannot speak for themselves, by promoting their legal standing and physical protection." Bureaucrats of the ministry set out to work with governments, central banks, and corporations to craft a new global economic system that promotes rapid decarbonization. The system incorporates various financial instruments (carbon credits, carbon taxes, carbon coins...) to incentivize both emissions reductions and carbon capture.

In the meantime, new technologies are being developed to alleviate climate change and its worst effects. Scientists and engineers from various countries cooperate to use some of these techniques to save the Arctic glaciers. The Arctic Ocean is dyed yellow to reduce the amount of sunlight it absorbs. Engineers pump meltwater out from the bottom of glaciers to stop them from falling into the ocean. Not all such technologies, however, are subject to concerted action among nations. Following the lethal heat wave, Indian government takes unilateral action to spray tens of billions of tones of sulphate aerosols into the atmosphere using aircraft, with an aim to mimic the cooling effect of large volcanic eruptions. This move creates controversy in the international community, with dissenting voices saying that the action is risky and against international law.

Kim Stanley Robinson's 2020 novel *The Ministry for the Future* is not the average science -fiction book (Robinson 2020). It begins in a world just a few years away rather than a hundred years. The events that unfold do not feel remote or improbable. It begins in a world just a few years away rather than a hundred years. The events that unfold do not feel remote or improbable. The scientific narrative is based on cutting-edge research that is currently underway, rather than full-blown speculation. Indeed, in the last few decades scientists have been working on various new technologies for *climate geoengineering* – i.e., "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change" (The Royal Society 2009). Specifically, prospects of spraying sulphates or other reflective aerosols in the atmosphere with an aim to cool down the Earth has been investigated by scientists under the name Stratospheric Aerosol Injection (SAI). If deployed successfully, these particles will spread around in the atmosphere, forming a reflective blanket covering the Earth. This way, the amount of sunlight that is reflected back to space will increase, the amount that reaches the surface will decrease, surface temperatures will decrease. However, current scientific understanding of SAI is very limited. Research up to now has relied solely on computer models and indoor experiments which can yield very different results than those arising from real world implementation of SAI. Therefore, there are many uncertainties around both the efficiency and the risks of this speculative technology.

Some risks and uncertainties about SAI have been much commented on. First, it is not clear how much of a cooling effect SAI can practically achieve. Second, even if it achieves a global average cooling, its effects on regional temperatures as well as precipitation will be uneven. Africa may get hotter and drier; the monsoon region may get wetter. Finally, and most importantly, worries have been expressed about an eventual *moral hazard*. The idea is that some political and economic actors may count on SAI to shirk from their responsibility to reduce GHG emissions. If GHG concentrations keep rising while we deploy SAI, and then we suddenly have to stop deploying it due to technical constraints or international disputes, then the temperatures will rise up very swiftly to what they would have been without the curbing effect of SAI. The harms from the *termination shock*, as it is called, will be even worse than runaway climate change since it will happen in such a short time.

Given these serious risks and uncertainties, one person might think that SAI can never come to be a feasible strategy against climate change in the future, and that a moratorium on research should be adopted. Another might think that SAI research is worth pursuing, but that it should be carefully regulated and monitored to prohibit premature or irresponsible deployment in the future. Still another might think that SAI is our only option left to avert the worst effects of climate change, that is why research should continue at full speed, without any constraints. Beyond what individuals would think, it is more important to know what the “people” would think on SAI as a collective. According to democratic principles, people should have a say in those decisions that would have important consequences on their lives. Decisions regarding the research and deployment of SAI will affect literally everyone on Earth as well as future generations. Both using SAI wrongly and failing to use it when it could have been used rightly can lead to catastrophe. Therefore, the interests of all these people should be represented in decisions taken on SAI research and deployment. However, there are currently no mechanisms in place which would let people learn about, scrutinize, and come to an agreement on SAI-related activities, and do so globally. This thesis aims to address this lacune by attempting to answer the question: *How can meaningful public participation in decisions related to SAI take place at a global scale?*

The question of public participation in SAI belongs in the broader question of public participation in science and technology. Science is usually thought of as an autonomous domain that should be free from any value influences to safeguard its objectivity. Therefore, public participation in science and technology issues would undermine the reliability of science. However, this classical view of the *value-free ideal* has been challenged by scholars. In the first chapter, Reviewing the literature in philosophy of science regarding the place of social and ethical values in scientific activities, I argue that despite common conceptions, scientists cannot avoid value influences and should not strive to do so. Instead, social and ethical values should have due influence on all decisions regarding science and technology. I conclude by endorsing public participation in science and technology as a way to ensure adequate value influences.

In the second chapter, I introduce the speculative technology of concern – i.e., Stratospheric Aerosol Injection (SAI). Reviewing the SAI literatures in both natural and social sciences, I elaborate on the possible benefits, risks, and uncertainties around SAI. Given its high stakes and global scale, I conclude that the case for public participation in science and technology becomes especially relevant in the case of SAI, and that it should happen at a global level.

Once I establish that public participation in SAI is necessary, I set out to investigate what kind of a democracy this participation should be based upon. I begin by a theoretical inquiry which draws upon three strands of thought: Philip Kitcher’s well-ordered science, deliberative democracy, and global democracy. Then,

I review the extant mechanisms for public participation in science and technology. Giving special attention to deliberative mini-publics, I review five mini-public designs that have been frequently used: Deliberative Polling, Citizens' Dialogue, Citizens' Jury, Consensus Conference, Citizens' Assembly. I conclude that Citizens' Assembly is the most appropriate design for public participation in SAI and make a proposal for establishing a Global Citizens' Assembly on SAI. I finish the thesis with a discussion on the limitations of my proposal.

2. CHAPTER 1 – A CASE FOR PUBLIC PARTICIPATION IN SCIENCE AND TECHNOLOGY

Why do we need public participation in science and technology? Isn't science an activity which should be isolated from social and political concerns to safeguard its reliability? Can lay people possibly guide the trajectory of science and technology in a meaningful way? This chapter makes a general case for public participation in science and technology based on one principal and two auxiliary arguments. The principal argument, called the *democracy argument*, has the following structure: Science and technology greatly impact the society as a whole. Contrary to the standard view, many decisions at the heart of science are value-laden decisions. Since value-laden decisions which greatly impact the society are political decisions, democratic principles require that the public should have due influence in the making of these decisions. The first auxiliary argument, the *sound science argument*, is as follows: The intrinsic value of science comes from its reliability. Value influences in science, when left unscrutinized, may impair reliability. While there are well-established mechanisms within science to impede illegitimate value influences, public participation -when exercised appropriately- may further help with this goal by unveiling possible biases that may inflict the scientific community as a whole. The second auxiliary argument is the *public trust argument*: Public interest is best served when the best available scientific knowledge is incorporated into public policy. Scientific knowledge can be better incorporated into public policy when there is public trust in science. Public participation can enhance public trust by improving public understanding of science and increasing public influence on science. The principal argument is sufficient to make the case for public participation in science and technology. In other words, our commitment to democracy itself is enough to make public participation in science both desirable and necessary. Other arguments serve as support for the case by demonstrating its additional benefits. These three arguments in favor of public participation in science also constitute the criteria for a good participation exercise. That is, we would desire any participation exercise to lead to more democratic decisions in science, to improve -or at least not deteriorate-reliability of science, and to increase -or at least not decrease- public trust in science.

First section explains the standard view of science according to which science should ideally be purified from social and ethical values. Second section rejects the standard view by demonstrating the value-laden decisions at all instances of the scientific enterprise. Third section elaborates on the three arguments for public participation in science, given that the value-free ideal does not hold.

2.1 Standard View of Science: Weberian Division of Labor, Value-Free Ideal

As the impact of science and technology on the political domain has expanded, theories on the proper relationship between science and politics emerged in parallel. The standard view of science in liberal democracies came to be one which sees science as an autonomous, value-free endeavor. One well-known formulation of this view can be found in the 1945 report of Vannevar Bush, *The Endless Frontier*. According to Bush, the benefits of science in the form of ever effective public policies will only be realized if science is kept autonomous from the rest of the society. Politicians and the public should not meddle with the inner workings of science because only scientists can reasonably assess which research will generate the most benefit. Interventions from outside with an aim to direct scientific research towards social priorities will only cause harm to science by impairing its objectivity. Therefore, public funds should be allocated to basic science in an unconditional manner, and scientists should be given the freedom to conduct the research they deem the most important. Their efforts will generate precious knowledge which will ultimately serve the society in the form of new technologies and better-informed public policies (Bush 1945).

Bush's advocacy of the autonomy of science was closely connected to Michael Polanyi's theory of scientific progress. Having developed it first in the 1940s, Polanyi makes a mature articulation of his theory in his 1962 essay *The Republic of Science*. According to Polanyi, science progresses most effectively when independent researchers have the freedom to pursue those questions in basic science that they find the most interesting, in whichever subjects they are curious about. In the long run, the results from these seemingly esoteric research initiatives are accumulated by an "invisible hand", leading to unforeseen discoveries which end up serving the public greatly. This model of scientific progress is analogous to the liberal economic theory of the free market. Progress will happen when the community of scientists are free from political interventions, and self-governing based on their proper internal standards. Benefits of science to the broader public will not be direct and immediate. Instead, they will occur cumulatively through trickle-down effects. Governments' efforts to guide science in desired directions undermine science instead of helping it advance because politicians cannot understand the complex inner workings of science and therefore cannot predict which research will lead to the most important advances (Polanyi 1962).

As can be seen, the standard view entails a strict division of labor between scientists and the public, one which is reminiscent of the Weberian division of labor between bureaucracy and politicians. Weber's ideal envisages that bureaucratic experts provide a neutral account of facts, and politicians make policies based on these facts (Weber 1949). Similarly, in the standard view of science, scientists provide the necessary expertise to realize public policies preferred by the people and its representatives. Public determines its ends according to the social values it upholds, politicians design public policies to realize those ends, and scientists come into the picture in the last instance, only to inform the politicians on the various means to pursue those ends.

This view relies on the assumption that social or ethical values have no bearing on the central aspects of science. Opening these aspects to the influence of social and ethical values would lead to wishful thinking and distort the objectivity of science. Therefore, according to the value-free ideal of science, the internal processes of scientific research, such as research design, hypothesis testing, and making inferences, should be as free as possible from all social and ethical values (Douglas 2009). An early expression of this view can be found in a 1942 essay by Robert Merton, *The Normative Structure of Science*. Merton argued that science as an institution should be guided by an "ethos of science". Consisting of a set of internal norms (universalism, communism, disinterestedness, organized skepticism), this ethos would be internalized by researchers and safeguard the integrity of science against encroachments of personal considerations or social and political values (Merton 1973*a*).

Writing in the 1930s and 1940s, Merton was concerned with the anguish science was going through in Germany and Russia under the yoke of totalitarian regimes. In Germany, science was being forcefully directed towards the practical needs of the Nazi regime, deprecating theoretical endeavors in "pure science". Even more serious, "non-Aryan" academics were being persecuted on racist grounds. Criteria for scientific validity and significance were determined by the dogmatic ideological tenets of Nazism instead of logic and evidence (Merton 1973*b*). Similar developments occurred under the other totalitarian regime of Stalinism in late 1930s. Facing a horrible failure in his collectivization policies in agriculture, Stalin was in search of a promising new way to increase yields quickly. “Western” genetic science was made the scapegoat for the failure. Genetic theories which emphasized the importance of inherited characteristics of crops were rejected and condemned as “bourgeois”. Prominent geneticists such as Nikolai Vavilov were persecuted as “counter-revolutionary” and left to starve in prison. Instead of genetics, a false theory called Lysenkoism, named after the fraudulent and incompetent scientist Trofim Lysenko was adopted. Lysenkoism gave undue weight to the impact of environmental factors on yields, which resonated perfectly with the Marxist ideology (Pringle 2008). Evaluated in the historical context, Merton’s worries about science becoming the “handmaiden” of politics were completely warranted.

The value-free ideal came to be widely accepted in the philosophy of science as from the 1960s. Isaac Levi’s prominent account of the value-free ideal admonishes that only epistemic values, i.e., those values internal to the scientific community such as simplicity, predictive power, and scope, are allowed to play a role to decide whether there is sufficient evidence for accepting a hypothesis. Since scientists adopt certain “canons of inference”, they should not worry about the social implications of making errors in their conclusions. Science’s only goal is “to replace doubt by true belief”, hence no other values than those values proper to science have a legitimate role to play during research (Levi 1962). Thomas Kuhn’s view of science as an isolated activity further consolidated the value-free ideal. Kuhn argued that detachment of the scientific community from the rest of the society was a prerequisite for the development of science. Science advances when researchers can focus on problems which are tractable with current knowledge and tools, without an obligation to consider whether they are also those problems which need to be addressed urgently according to politicians and society (Kuhn 1962, 164).

In the following section, I will argue that value influences in science are not problematic per se. The problem with Nazi and Soviet sciences was not that there were value influences in science, but that those value influences were illegitimate. Indeed, value-free ideal is untenable because value-laden decisions are inevitable at all steps of scientific enterprise, including the internal steps of research design and methodology. Moreover, I will argue that adequate influences of social and moral values in science are not only inevitable, but also desirable and necessary.

Before moving on, it is important to note that the value-free ideal does not promote complete disregard of social and ethical values in science. First, it is widely accepted that ethical values have a role to play in science. However, under the value-free ideal, their influence is limited to specific issues such as respect towards colleagues and students, academic integrity, appropriate treatment of human and animal subjects, and observance of codes and regulations to avoid harms to people while conducting research. Together, these issues constitute what is called procedural ethics (Schienke et al. 2011) - i.e., concerns about the integrity of science and the harms immediately related to research. According to the value-free ideal, broader ethical implications which may result from the conclusions of research and their application in the real world have no place in scientific reasoning. Second, social values are assigned a well-demarcated role as well under the value-free ideal, at least by some of its proponents. Even though he considered disinterestedness as an integral part of the ethos of science, Merton argued early on that disregard of scientists for the social implications of their research risked undermining public trust in science (Merton 1973*b*). Similarly, as will be elaborated in the next section, philosopher Hugh Lacey argued that prioritization of particular research areas, and adoption of specific “research strategies” to study these areas both involved value-laden decisions. However, like other advocates of the value-free ideal, he denies a role to social values in the central processes of science such as evidential standards (Lacey 1999). Therefore, value-free ideal can be more accurately named as the “internal scientific values only when performing scientific reasoning” ideal (Douglas 2009, 45).

2.2 Value-Laden Decisions in Science

Contrary to the value-free ideal of science, many decisions related to science and technology are value-laden decisions, meaning decisions that are not entirely based on logic and evidence. There are value-laden decisions before, during, and after the conduct of scientific research. While some of these decisions are obvious and uncontested, others are hidden behind technical aspects of science. Usually, value choices made in the external processes, i.e., the processes before and after the conduct of research, are easily detectable. However, many value choices that take place in the internal processes, i.e., during the research, go unnoticed and they are left to the judgment of scientists. This section explores how social and ethical values are relevant to many decisions in science, such as decisions on which topics to study, how to study those topics, which conclusions to draw, how to communicate these conclusions, and what to do with those conclusions.

2.2.1 Setting of the Research Agenda, Allocation of Funding

Even though the image of the endless frontier insinuates that society can promote all kinds of scientific research simultaneously, in the real world we have limited resources to invest in science. Among all the possible scientific projects that can be pursued at any given time, only a select number of projects will actually be pursued. The decision of which research areas will be prioritized and funded, and which areas will be neglected, is based on judgments about what type of knowledge is worth obtaining and what type of knowledge is dispensable, at least for the time being. Hence, it is a value-laden decision (Lacey 1999). Considering the great impact of science on society, this decision effectively becomes a choice of which policy options and technologies will be available to the society in the future. To put it succinctly, it is a decision over what kind of world we will live in. Scientific community usually has different priorities than society when it comes to choosing research projects. For example, they may favor research which they find interesting, or which will promote progress within their own discipline. It is not a given that progress in science will lead to public good regardless of the direction of research (Sarewitz 1996). Therefore, when this decision does not engage the public and is left to scientists alone, the prospective policy options of a society become narrowed down in an unaccountable way (Sarewitz 2010). Public participation in choosing prioritized research areas can direct science to address important social needs rather than giving undue weight to esoteric research, research which benefits particularistic interests, and most importantly, research which may result in harms to society. For example, only 2.4% to 4.6% of all science funding in the world has been allocated to research on climate change during the period from 1990 to 2018 (Overland and Sovacool 2020). Considering the gravity of the potential consequences of climate change and increasing public concern over this issue, public participation over funding decisions has the possibility to change the current picture.

2.2.2 Research Strategies

Once the topics of research have been selected, value-laden decisions over how to study these topics should be made. This involves decisions over background assumptions, research questions, theories, and methodology. Some roles for values in these decisions are widely acknowledged. For example, the prohibition of outright unethical methods, such as inappropriate experiments on human subjects or rigged methods which generate predetermined results, is uncontested. However, there are also more subtle value-laden decisions in how to study a topic which needs to be pointed out. The same topic can be studied in very different ways, by adopting different "research strategies", and choosing one strategy over another will at many instances promote some values rather than others and will determine a direction for society (Lacey 1999). For example, action on climate change can be pursued following different strategies such as abatement, mitigation, and adaptation.[1] Abatement strategies aim at reducing GHG emissions, whereas mitigation strategies are used to reduce GHG concentrations already present in the atmosphere. Adaptation strategies refer to measures to reduce the negative impacts of unavoidable climate change (Jamieson 2014). These different strategies will require different types of scientific research. For example, developed countries tend to give almost exclusive weight to research on abatement and mitigation, neglecting adaptation which will be vital for developing countries when they will confront the worst consequences of climate change (Gardiner 2011). This bias towards abatement and mitigation is accompanied by another strong bias towards natural sciences in climate research, neglecting the potential contribution from social sciences which may prove to be crucial in the future. Efforts to increase our predictive capacity of climate events through research in natural sciences is certainly of utmost importance. However, actions to fight climate change will ultimately take place in human societies. They will require deep and rapid transformations in all domains of human activity at all levels. People will have to change their well-entrenched habits in painstaking ways. Insights from social sciences such as economics, political science, sociology, and psychology would be essential to succeed in this difficult task in effective and equitable ways. Nevertheless, natural and technical sciences received 770% more funding than the social sciences for climate change research in the period between 1990 and 2018. Moreover, almost no social science research on climate change was conducted before 1990 (Overland and Sovacool 2020). Again, public participation in choosing research strategies may help steer science in directions which will address the most pressing issues related to climate change, such as adaptation of the most vulnerable communities and effective ways to implement climate action in our present societies.

2.2.3 Underdetermination, Background Assumptions, Modelling Choices

Another aspect of science which requires value-laden decisions are the assumptions that scientists have to make to be able to conduct research in the first place. As opposed to one common view, scientific theories are not accepted or re-

[1] According to the classification of Jamieson, Solar radiation management is the fourth distinct category of climate change action. Since I discuss this category extensively in chapter 2, I opt to exclude it here.

jected solely based on evidence. To be able to pursue particular research questions and answer them based on particular theories, scientists have to make some background assumptions on what counts as evidence, which methods are the best for collecting and analyzing evidence, how to interpret evidence, and how to deal with limitations in evidence, and so on. To put it in a single word, all theories are *underdetermined* by evidence. Underdetermination of scientific theories was first put forth by French physicist Pierre Duhem at the turn of the 20th century. Duhem argued that physical theories or hypotheses are empirically tested not individually, but always in groups. In other words, we can formulate empirical predictions from a hypothesis only in combination with other hypotheses and background assumptions. Therefore, when an empirical prediction does not hold against the evidence, we cannot possibly know whether it is the main hypothesis or one of the background hypotheses and assumptions that should be disconfirmed. Our response to a falsified empirical consequence is underdetermined by the evidence. As a result, there can never be a "crucial experiment" which would lead to a definite confirmation or refutation of a theory against its rivals (Duhem 1954).

Duhem considered underdetermination as a problem regarding solely the confirmation of physical theories. Philosopher W. V. O. Quine expanded the concept of underdetermination, arguing that it poses a problem for the confirmation of all scientific theories, and even further of all knowledge claims. According to Quine, the totality of our knowledge or beliefs, whether they be sophisticated scientific theories, trivial facts about everyday life, or statements of logic and language, are interwoven into a complex body of knowledge which is hit by empirical experience at its boundaries. Since all of our beliefs are intricately linked together, no particular experience corresponds to a particular belief. Therefore, following Duhem, when an experience is in discord with our beliefs as a whole, that experience does not determine which particular beliefs are to be revised and which should be kept intact. In other words, the decision about which revisions to make in our beliefs in the face of a new and challenging evidence is underdetermined by that evidence. All of our beliefs, including scientific hypotheses and theories, are hold to empirical test not individually, but as a whole (Quine 1951).

Feminist scholars have argued that in the face of underdetermination, value judgments come into play in determining which beliefs are to be discarded and which to be safeguarded. According to Helen Longino, those background assumptions that are adopted when testing a theory stem in part from the personal values of scientists, which in turn reflect power relations among the society he is a member of. This results in the systematic exclusion of some types of theories from scientific practice, ending in a biased body of knowledge. To remediate this situation, mechanisms should be developed to discover and scrutinize background assumptions, making clear why some assumptions are being made rather than others (Longino 1990).

Background assumptions play crucial roles in scientific models as well. Based on what the model is built to predict, some aspects of the world will be given more weight, and some will be excluded. Moreover, optimizing or "tuning" a model to best fit the available data will often require some trade-offs, so that increased accuracy in some phenomena will end up decreased accuracy in others. For example, a model that is tuned to predict distribution of precipitation in a given region may have decreased accuracy in predicting extreme weather events. Or, a model can prioritize predicting gradual changes in the climate -as current models do-rather than predicting worst-case scenarios that would occur with rapid warming (Intemann 2015). Deciding on which phenomena merits more accurate predictions involves value judgments about which phenomena are more important to know. Since predictions from climate models will form the basis of climate policies under which many people will live, it is important that such value judgments be informed by social needs and priorities.

Values are also in play in the economic models of climate change. An influential report, The Stern Review which is named after its lead author economist Sir Nicholas Stern, triggered controversy when it was published in 2006. According to the report, investing significant amounts of money into climate action in the present would be less costly than deferring climate action to future generations. Therefore, the report concluded that we should better start taking aggressive abatement and mitigation measures today. Other prominent economists such as William Nordhaus criticized the report by its choice of discount rate[2] which is much lower than the one conventionally used in the discipline of economics. Nordhaus argued that by choosing an extraordinarily low discount rate, Stern managed to make future costs appear much higher than what previous studies had found. When the conventional discount rate is used, it seemed more sensible to prioritize economic growth in the present by postponing serious climate action (Weitzman 2007). Choice of an appropriate discount rate may first seem like a technical issue that should be settled according to disciplinary conventions. In fact, it is a value-laden decision weighing the importance of the costs to the present people against the importance of the costs to the future people. In other words, it is a matter of intergenerational justice. Choices about economic models may also involve values pertaining to intragenerational justice. For example, if a model includes only aggregate information about the costs, but no indicator of how these costs are distributed among different groups, then a

[2] Discount rate in economics is the rate at which a future benefit is considered as less significant compared a similar benefit in the present - e.g., $110 in the future is worth $100 today with a discount rate of 10%.

climate change strategy which seems the most efficient according to this model may in fact be placing undue burden on some groups, especially marginalized groups such as poor people in poor countries (Gardiner 2011). Thus, scientists should thoughtfully consider what they choose to model and how they choose to model it, and the implications of these choices for social and ethical values (Schienke et al. 2011). Public input could greatly assist scientists in this task.

2.2.4 Dealing with Uncertainty, Epistemic Risks

Values also play a significant role in responding to uncertainty in science. Underdetermination in science suggests that a hypothesis is never completely verified, that there is always an "inductive gap" between the available evidence and the conclusions that scientist make. In other words, there is always some level of uncertainty around scientific findings. This ineliminable uncertainty in science creates an endemic *inductive risk* of making errors in accepting or rejecting a hypothesis. To be exact, one can mistakenly accept a hypothesis that is false, or reject a hypothesis that is true. The first type of error is called a false positive, whereas the second type is called a false negative. Usually, reducing risks of both false positives and false negatives require unfeasible changes in the research design. Therefore, the scientist is usually faced with a trade-off between the risks of the two types of errors. How do the scientists decide whether to accept or reject a hypothesis in the face of inductive risk? Put differently, how do scientists determine their evidential standards, i.e., the amount of evidence required to accept a hypothesis? Traditionally, scientists choose conservative statistical significance levels with an aim to avoid false positive errors. In other words, scientists as a community do not want to make claims which eventually turn out to be false. However, Heather Douglas argues that social and ethical values have a role to play when deciding on evidential standards, since they may end up in decisions that greatly affect people (Douglas 2009).

Douglas' argument from inductive risk is based on Rudner's argument who wrote back in 1953, before the value-free ideal took over the philosophy of science. According to Rudner, the designation of evidential standards should be based on ethical considerations about which type of error is worse to make under given circumstances, thinking about the potential consequences of each (Rudner 1953). Douglas' contribution is the distinction between direct and indirect influences of values in science. Values have a direct influence in making a decision if they act as a direct motivation for that decision. For instance, a value directly influences the decision of accepting a hypothesis if it acts as a reason in itself in accepting that hypothesis, in the same way as evidence does. Values have an indirect influence in making a decision if they act to evaluate the seriousness of the inductive risk around a claim, helping to decide what would be considered as sufficient evidence for the claim, in other words what level of uncertainty would be acceptable. Besides hypothesis testing, other epistemic decisions involve inductive risk such as characterization and interpretation of evidence, integrating findings which come from multiple studies, and extrapolation of results (Douglas 2009). According to the categorization of Justin Biddle and Rebecca Kukla, the concept inductive risk is reserved to the risks associated with hypothesis testing. They argue that Douglas' expansion of the term to comprise other types of risks is not warranted, since these risks do not involve induction in the accurate sense. To refer to these other risks, they introduce the broader term *epistemic risk* which also comprises inductive risk in its narrow sense (Biddle and Kukla 2017). Throughout the thesis, I will comply with this categorization.

According to Douglas, values can play both direct and indirect roles in external phases of science such as choice of research topics, theories, and research questions, but their role should be limited to indirect influences in the epistemic decisions. A direct role for values in epistemic decisions central to science is not acceptable because this would lead to wishful thinking. Scientists would accept or reject hypotheses simply based on whether it conformed with their values, regardless of available evidence. The fundamental value we assign to science is that it provides us with evidence-based, reliable knowledge. Letting values compete with or replace evidence in those decisions about what we deem to be true would destroy the very reason we do science. Indirect influences, however, are both legitimate and necessary in epistemic decisions. In the face of uncertainty, scientists have a moral responsibility to consider the social and ethical implications of making an error in accepting or rejecting a claim. Just like everyone else, scientists have an ethical responsibility to reasonably consider the consequences of their choices to avoid harm to others. Since scientific claims are authoritative claims, meaning they are taken to be reliable information by the public and serve as basis of public policy, scientists should weigh the potential consequences of pronouncing a false negative or a false positive conclusion in the face of uncertainty. Usually, these kinds of decisions are made by communities of scientists instead of by individual scientists (Douglas 2009). For example, each scientific discipline typically has adopted a conventional statistical significance level such as 90%, 95%, or 99%. Similarly, scientists may choose to adopt community guidelines for the interpretation of ambiguous data (Wilholt 2009). Making a collective choice can limit unwarranted influences of personal values, hence it is more justifiable than individual decisions. Still, it might be that the scientific community as a whole is biased in ways that undermine social and ethical values. Therefore, it is important that scientific communities periodically discuss their reasons for adopting certain standards of evidence, and do this in a way that is transparent and open to public scrutiny (Elliott 2017).

2.2.5 Framing and Language

Once scientists finalize their studies and arrive at certain findings, they should also take value-laden decisions on how to communicate these findings with the public. Scientists have the option to avoid drawing any straightforward conclusions and to simply present the evidence as it is. This cautionary approach may be useful in cases where there is limited evidence, as it would protect scientists from making false statements and consequently losing their reputation. However, this approach has the disadvantage of confusing the politicians and the public since they cannot understand raw evidence without at least some interpretation by the scientists. Hence, with this approach there is a high risk of misunderstanding and inappropriate policies which could harm society (Cranor 1990). Moreover, in many instances, scientists find themselves compelled to clearly inform the public even in the face of limited evidence. It would be unreasonable to avoid making any conclusions until they had decisive evidence, which in fact may never arrive (Biddle 2013). That is why, such an approach to science communication is often not feasible. A second approach would be the opposite of the cautionary approach, namely communicating the conclusion that scientists think is best supported by available evidence in a bold, direct manner. The advantage of this bold approach is that there is little risk of misunderstanding. Here, the scientists provide policy makers and the public with a clear view. Another advantage of this approach is that it can stir public attention in subjects which need immediate action. Its disadvantage is that if the conclusions are false, scientists will lose their reputation and trust in eyes of the public. Also, this may cause unnecessary panic and alarmism among the people. For example, in 1988, climate scientist James Hansen made a bold testimony to the congress that global warming was directly linked to human emissions of GHGs, and that it was already happening. Many of his colleagues criticized Hansen by asserting that he had made an overly confident claim, and by doing so had compromised his objectivity and the public trust in climate science (Kerr 1989). A more balanced approach would be to communicate again the best-supported conclusion, however this time with adequate hedging and qualifications to acknowledge the uncertainty around that conclusion. However, this strategy of communication also bears some risks. For instance, the nuances made by scientists may be “lost in translation” as it passes through the media. Or, they may be overemphasized by skeptics with an aim to cast doubt on the validity of the conclusions (Elliott 2017).

Public participation in science would allow scientists to better communicate their findings. Engaging in continuous dialogue with the public, the scientists would have the opportunity to explain what the uncertainty around their findings exactly meant, and how they chose to respond to that uncertainty. This way, they would have to worry less about being misunderstood or about trying to find strategic ways to communicate their conclusions, which may even be deemed dishonest at times.

In science communication, values also play an important role in the decisions about the use of language. The choices of terminology, categories, metaphors, and framing usually uphold some values over others in subtle ways and being completely neutral is not feasible in many cases. For instance, In the case of climate change, some scholars replaced the metaphor of “the greenhouse effect” with “global warming”, arguing that this term was better at directly communicating the consequences of the effect in question. Later, “global warming” was replaced with “climate change”, in part because the former term was deemed open to misunderstanding by the public. Particularly, this term did not have any connotations about the important climatic changes other than changes in temperature, such as change in precipitation patterns and the likelihood of extreme weather events. Hence, the term which is most commonly used today, “climate change”, was adopted (Gardiner 2004). There was also a political reason for the adoption of “climate change”. The US Republican Party had discovered that this term invoked less alarming impressions than “global warming” among their constituencies (Pielke 2007). Therefore, scientists have to critically evaluate the implications of using particular terms in communicating scientific information to public. They should assess their choices of language in terms of their accuracy, clarity, and compatibility with social and ethical values. Unavoidable connotations which support some values should be acknowledged, and foreseeable misunderstandings should be addressed (Elliott and McKaughan 2014; Larson 2011).

2.2.6 Implementation

Finally, of course, value decisions are relevant for the translation of science into public policy. In principle, public should have the ultimate say over how scientific information will be used within public policy, and over which technologies should be adopted and how they should be employed. This is an uncontested role for values in decisions about science and technology. However, since the available scientific knowledge determines the range of available policies, and the former is determined by the earlier decisions taken before and during research, it is important that public participation does not remain restricted to these decisions taken at the very end of the scientific process.

Before proceeding to the last section of this chapter, it is important to note that value influences in science can be intentional or unintentional. That is, scientists may be consciously or unconsciously be influenced by the personal and social circumstances in which they find themselves. For example, after Hansen's testimony in 1988, an organized climate change denial movement has emerged. This movement worked in the service of powerful vested interests such as fossil fuel and automobile companies and insisted on denying climate change even as evidence in support of it grew bigger. Incorporating several reputable scientists, the denialist research was very influential in discouraging H. W. Bush administration from adopting climate change regulations such as carbon taxes and restrictions on fossil fuel usage. Tobacco, chemical, fast food, and pharmaceutical industries have also sponsored rigged research with an aim to cast doubt on the environmental and public health harms of their products so that their profits would not diminish (Oreskes and Conway 2011; Sismondo 2008). These are obvious examples of illegitimate value influences since the scientists in question deliberately allowed their personal values promoting free-market capitalism and the values of their sponsors promoting unhindered industrial activity to be direct reasons to arrive at conclusions. These values made them ignore or distort evidence or insist on objections which had already been thoroughly addressed by the scientific community. In short, illegitimate value influences injured their objectivity through wishful thinking. Instead of resorting to direct manipulation of data and findings, scientists may choose to promote industrial values against environmental and public health values by opting for very high standards of evidence to accept that the harms exist (Elliott 2017). This time, the values would have an indirect influence. Still, this would be an unacceptable influence since scientists consciously neglect their moral responsibility to consider the consequences of their research findings based on social needs.

In many cases, however, scientists uphold some values over others unintentionally in their decisions, even though they think of themselves as being neutral. For example, an economist may choose a discount rate merely due to the convention within the discipline. He may not have any intention to trivialize the interests of future people. Still, this choice may lead to conclusions that end up doing so. These value judgments can be subconscious as well (Elliott and Resnik 2014). Or it can be that scientists as individuals do not have the power to make these value judgments themselves. They may find themselves compelled to study a particular topic in particular ways due to institutional or financial incentives. In any of these cases, their decisions still end up supporting some values over others. Hence, scientists should be reflective about the value-laden choices that they make and be transparent about them so that others can also scrutinize these choices. All people have the moral responsibility to consider the consequences of their actions. Everyone should aim to avoid harm to others by recklessness or neglect and strive to benefit others if it is not too demanding. Scientists are not exempt from this duty (Douglas 2009). In the end, societies support science and assign it authority because they believe it will benefit them. Hence, scientists should be careful about incorporating the right values in their research and about doing so in appropriate ways. Public scrutiny of value influences in science would help achieve transparency and alignment with social and ethical values (Elliott 2017).

2.3 Discussion

In the previous section, I argued that value-free ideal is both unattainable and undesirable. It is unattainable in that all steps of scientific enterprise involve value-laden decisions. Choices about which research topics to study, how to study these topics, how to arrive at conclusions and what do to with those conclusions cannot be settled solely based on criteria internal to science. In many instances of science, value judgments are inevitable. Value-free ideal is also undesirable because moral responsibilities of scientists require them to account for the consequences of their decisions before, during, and after research. Doing so entails opening science up to appropriate value influences. Indeed, accepting the value-ideal does not purify science from values, it just hides away the value influences at work, including illegitimate influences (Elliott 2017). Since science cannot be reasonably be purged from social and ethical values, insisting on the value-free ideal in a sense amounts to wishful thinking.

Given that value-free ideal does not hold, the Weberian division of labor also becomes untenable. Let us first reiterate the *democracy argument*: If many important decisions in science are value-laden decisions, and if science and technology greatly impact the society, these decisions effectively become political decisions. Democratic principles require that the public should have due influence on these decisions. Determination of means cannot be left to experts since this is not a strictly technical process. Moreover, the public cannot determine on its ends, or even contemplate on them, without drawing upon the expert knowledge on the available means (Kurtulmuş Forthcoming). If the means are being shaped by value-laden decisions of scientists, and if these means will predetermine the options we have for our ends, then leaving these decisions only to the experts and their sponsors is unacceptable. As science and technology have the potential to generate both great benefit and great harm to the public, everyone should have a say in decisions which will affect them, and which are not settled by the evidence. Autonomous science, in this regard, comes to seize a political power that rightfully belongs to the public (Pamuk 2017). Hence, the value-decisions that scientists make in all steps of the scientific process should be opened up to critical scrutiny through public participation. While scientists have a responsibility to avoid being negligent or reckless when making these decisions, the best way to account for the values, preferences, interests and aims of the public is to allow them to exert influence on these decisions, especially if public funds are being used and there is risk of harming important public interests (Kitcher 2001, 2011).

Secondly, public participation can improve science by increasing its reliability. The *sound science argument* states that illegitimate value influences in science may go unnoticed if they are not adequately scrutinized. Actually, scientific community has well-established mechanisms such as peer review and conventional evidentiary standards to weed out illegitimate value influences. Moreover, scientists are increasingly working in groups and networks. They share their data, materials, methods, and findings with an aim to conduct transparent and standardized research. Also, this community is increasingly more diversified and interdisciplinary work is being encouraged. For example, in the case of climate change, international climate policies are informed by the Intergovernmental Panel on Climate Change (IPCC) which synthesizes many studies from diverse disciplines to come up with comprehensive reports integrating diverse perspectives. Such efforts are deemed to make science more reliable by relying on the collective wisdom of the scientific community (Elliott 2017). Nevertheless, all these may still fall short of properly integrating social and ethical values in science. First, even though its diversity has been increasing in the last decades, scientific community still lacks adequate representation of all relevant demographic groups in the world. Second, scientists may have some specific values that they have developed during their professionalization. These values may possibly conflict with broader social values, leaving the entire scientific community biased (Douglas 2009). Therefore, public participation is necessary to detect illegitimate value influences and to align science with social needs and priorities, even in presence of a diverse and vigilant scientific community.

Another way in which public participation can improve scientific knowledge if by promoting epistemic diversity and incorporating local knowledge in science. Engaging different groups, especially marginalized groups in science will open science up to alternative theories and to questions which may have never occurred to professional scientists. Local knowledge of communities may enrich scientific research by introducing unique experiences, perspectives, and insights of lay people. Particularly, traditional ecological knowledge of indigenous populations about the environment they have inhabited since centuries may prove essential in reconsidering the findings of professional science (Irwin 1995).

Thirdly, *public trust argument* states that public participation is also desirable because it can foster public trust. Public trust is necessary for realizing the full benefits of science. When trust in science is lacking, the public or its representatives will be less likely to heed the advice of scientists. When the people have a chance to understand at least some of the key aspects of science, and when they are given the rightful opportunity to influence these key aspects, we can reasonably expect that people will trust science more. This, in return, will facilitate the incorporation of scientific knowledge in public policies. Ultimately, public interest will be served by policies which are both evidence-based and representative of social values.

As a final word, public engagement may also help scientists by sharing their responsibility to consider the consequences of their value judgments they inevitably make during research. When reflecting on the social and ethical ramifications of these judgments, scientists may find themselves overwhelmed trying to strike a balance between different values and to make the most appropriate decision. Public engagement can remove part of this burden from the scientists. However, public participation would not exonerate scientists from their responsibilities because they will always be the first to confront new scientific findings whichmay have important consequences for the public (Douglas 2009).

3. CHAPTER 2 WHY PUBLIC PARTICIPATION IN STRATOSPHERIC AEROSOL INJECTION (SAI)? VALUE-LADEN ASPECTS OF SAI RESEARCH AND DEPLOYMENT

In the first chapter, I have made a case for public participation in decisions related to science and technology in general terms. My main argument was that since there are value-laden decisions at all stages of science and technology, and since many of these decisions have far-reaching consequences, the public should be able to meaningfully influence these decisions. In this chapter, I explore the ramifications of this same argument for Stratospheric Aerosol Injection (SAI). I do so by displaying how values come into play in present and possible future decisions pertaining to the research and deployment of this technology, decisions which have serious social, political, and ethical implications. First section introduces climate geoengineering in general and SAI in particular as proposed strategies to offset climate change. Second section explains the uncertainties and risks in SAI from the perspective of natural sciences. Third section explores the implications of these uncertainties and risks for society, politics, and ethics. Final section reflects on the value-laden decisions that SAI involves and makes the case for public participation in SAI research and deployment.

3.1 Climate Geoengineering and Stratospheric Aerosol Injection (SAI)

Climate change is one of the most challenging problems humanity has ever faced. Increased concentrations of GHGs in the atmosphere resulting from human activities, mainly from burning fossil fuels, are causing changes in the climate. The most salient change is an increase in average global temperatures, but there are many other wide-ranging and serious environmental impacts related to climate change such as heat waves, wildfires, droughts, hurricanes, floods, melting of polar ice, sea-level rises, ocean acidification, and increase in vector-borne diseases. All these impacts have a heavy toll on natural systems as well as human systems which depend on the latter for their livelihoods. For instance, climate change poses serious risks on crops, fisheries, and water resources (IPCC 2014). Earth's average surface temperature has already increased more than 1 °C since the beginning of the Industrial Revolution. According to the 1.5 °C Special Report of IPCC, if we limit average global warming to 1.5 °C above pre-industrial levels, we can offset many of the worst climate risks (IPCC 2018). To achieve this goal, decisive and quick action must be taken for abatement and mitigation[1], i.e., to decrease GHG emissions and concentrations, so as to hit net zero emissions by the middle of this century. Technologies to achieve this goal are both available and affordable (The Royal Society 2009). Unfortunately, climate politics has for most of the time been impaired by inertia due to international conflicts, vested interests, and general complacency. Consequently, global emissions continued increasing at a dangerous pace, followed by an alarming increase in average temperatures which made 2015-2019 the hottest years ever recorded. Recently, a momentum has emerged with large emitter countries such as the United States, China, and the UK placing new ambitious pledges to decrease their emissions. Nevertheless, the current pledges still commit the Earth to an average warming of 2.4 °C by the end of this century (Climate Action Tracker 2021).

Given the dismal failure to deal with climate change seriously, some have started considering additional ways to avoid the worst climate risks, including climate geoengineering strategies. Climate geoengineering is defined as "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change" (The Royal Society 2009). While the first ever proposals for geoengineering go back as far as 1965 (President's Science Advisory Committee (PSAC) 1965), serious consideration of these techniques started with the 2006 essay by climate scientist Paul Crutzen (Crutzen 2006). Since then, several prominent research projects were initiated in Europe, the United States, Australia, and China (Forum for Climate Engineering Assessment (FCEA) 2018) and authoritative reports have been published, most notably by the Royal Society in the UK (The Royal Society 2009) and the National Academies in the US (National Academies of Sciences and Medicine 2021; National Research Council 2015*a*,*b*).

Climate geoengineering techniques are generally grouped under two categories. The first category, called Carbon Dioxide Removal (CDR), aims to remove

[1] IPCC uses mitigation to designate activities aimed at both decreasing emissions and increasing sinks. For instance, afforestation counts as mitigation. Throughout the thesis, I use Jamieson's categorization according to which abatement designates decreasing GHG emissions, and mitigation designates decreasing GHG concentrations.

CO_2 directly out of atmosphere and sequester it in a safe depository. Some of the considered CDR methods are large-scale afforestation, ocean fertilization, enhanced weathering, bioenergy with carbon capture and storage (BECCS), and direct air capture (DAC) technologies (The Royal Society 2009). Because CDR technologies aim to decrease CO_2 concentrations, they are also called negative emission strategies, and they can be placed under the mitigation category of climate change strategies. There are still many uncertainties around the effectiveness, costs, and negative impacts of these technologies. For instance, ocean iron fertilization requires intervening in natural systems which may cause serious perturbations (National Research Council 2015*a*). Likewise, BECCS requires large-scale land use changes which not be ecologically and socially sustainable (National Academies of Sciences and Medicine 2019). Moreover, CDR methods are expected to show their effect very slowly over several decades, just as global warming unfolded over a long period. It is not certain whether affordable and effective CDR methods will be available in due time. Nevertheless, CDR methods are developing fast, and they have already become part of the "default technology mix" of IPCC net zero scenarios (Lenzi et al. 2018).

Second category is called Solar Radiation Management (SRM) technologies. These technologies aim at decreasing the surface temperatures by reducing the amount of solar radiation that is absorbed by the Earth. They do so "by increasing the amount of sunlight that the atmosphere reflects back to space or by reducing the trapping of outgoing thermal radiation" (National Academies of Sciences and Medicine 2021). Some of the methods that have been proposed so far are painting roads and buildings white, making crops more reflective by genetic engineering, placing mirrors on deserts, ocean, and even space (The Royal Society 2009). However, the SRM methods that now attract the most attention are the three atmospheric-based methods: Marine Cloud Brightening, Cirrus Cloud Thinning, and Stratospheric Aerosol Injection.

Marine Cloud Brightening (MCB) aims to increase the reflectivity of marine clouds closer to the ocean surface by spraying salt water within them. Available research which commonly observes ship tracks as an analogue and has found that MCB can be effective in some circumstances. However, there are uncertainties around the large-scale climate impacts of MCB. MCB is intended to be used for regional interventions such as current research in Australia to save coral reefs. There have so far been two MCB experiments, one off the coast of Monterey, California in 2011 (Russell et al. 2013), the other off the coast of Townsville, Australia in 2020 with an aim to protect the Great Barrier Reef (Saving The Great Barrier Reef (SGBR) 2021).

Cirrus Cloud Thinning (CCT) envisages increasing the outgoing infrared radiation by making cirrus clouds -ice clouds in the upper troposphere- more transparent. These clouds are known to warm the planet, since they trap outgoing longwave radiation more than they reflect incoming solar radiation. By making these clouds thinner, we could theoretically achieve a net cooling. This is the SRM strategy that we currently have the least knowledge of. The few existing CCT models have generated contradictory results because there is very limited knowledge on cirrus cloud properties and how to alter these properties. That is why, at the moment there is no discussion of how CCT can be practically deployed (National Academies of Sciences and Medicine 2021).

The focus of this thesis is Stratospheric Aerosol Injection (SAI) which is the most researched SRM approach to date, and the one that is the best understood. SAI is a strategy to increase the reflectivity of Earth by adding aerosols -small reflective particles- such as sulfates into the stratosphere. The inspiration for this approach came from a natural analogue: large volcanic eruptions emit considerable amounts of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) into the stratosphere, which then form sulfuric acid (H_2SO_4) through oxidization and subsequently sulphates. For instance, the 1991 eruption of Mt. Pinatubo in the Philippines is estimated to have decreased the average global temperatures by 0.5 °C for at least one year (IPCC 2013). The cooling effect from volcano eruptions is global since the aerosols quickly spread in the stratosphere in a uniform manner. SAI aims to mimic this effect by injecting either "aerosol precursor gases" or directly sulfates into the stratosphere (National Academies of Sciences and Medicine 2021).

Research on SAI has so far continued using computer modeling. No outdoor experiments have been conducted except for a small one in Russia (Hsu 2009; Izrael et al. 2009). There was a planned outdoor test within the scope of the Stratospheric Particle Injection for Climate Engineering (SPICE) project funded by the UK government (SPICE N.d.). It would be a test only of the delivery mechanism -a 1-km high hose tied to a tethered balloon- by spraying a small amount of water instead of sulfates. Still, the test was opposed by the environmental NGOs in that it would pave the way to large-scale experiment and eventual deployment (Hands Off Mother Earth (HOME) 2011). The test was postponed and subsequently cancelled, citing lack of governance mechanisms for SAI research and possible conflicts of interest due to patent issues (Cressey 2012). At the moment, a research team at Harvard University is planning a small outdoor experiment called Stratospheric Controlled Perturbation Experiment, SCoPEx for short, which will probably take place in Sweden (The Keutsch Group N.d.). Differently from the cancelled SPICE test, this experiment aims to understand the behavior of aerosols in the stratosphere. A testbed will be elevated into the stratosphere using a balloon, then a small amount of water ice -and possibly some other materials- will be released into the air to monitor the physical and chemical reactions of the aerosols through specialized measuring instruments. Similar to the SPICE test, SCoPEx has attracted severe criticism from the NGO's even though it is of too small a scale to cause any discernible impact on the environment (Geoengineering Monitor 2020). Facing opposition from environmentalists as well as from Scandinavia's indigenous Saami community (Saami Council 2021), the advisory committee appointed to oversee the project recommended delaying a test flight that was scheduled for June 2021, with an aim to allow for robust public engagement (SCoPEx Advisory Committee 2021).

Available research suggests that climate geoengineering strategies may help us avert devastating harms from dangerous climate change if they can be successfully employed. However, there is also considerable amount of controversy surrounding these speculative technologies. In general, CDR methods are thought to be more acceptable than SRM, in particular SAI (Morrow, Kopp, and Oppenheimer 2009). On the one hand, CDR would return the climate system closer to its pre-industrial state by reversing the main physical mechanism through which humans set off the climate change in the first place. On the other hand, SAI would only alleviate the symptoms of climate change by manipulating the amount of sunlight that Earth absorbs. CDR gives the impression of being a cure, whereas SRM seems more like a symptomatic treatment which does not address the main cause of the disease. However, compared to CDR, SAI has the advantage of being a relatively inexpensive, technically feasible, and effective method which could provide considerable cooling in a few years of time (Barrett 2008; Keith, Parson, and Morgan 2010). These characteristics may present SAI as a fast and cheap "fix" to the worst effects of climate change that would occur if we surpassed certain critical thresholds (Keith, Parson, and Morgan 2010). SAI is also proposed as an insurance plan against "climate emergencies" such as rapid melting of the Arctic ice and tundra to avoid abrupt sea-level rises and release of methane (MacCracken 2009; Morgan and Ricke 2010). Others view SAI as a strategy for "buying time" until enough political will is mustered to take drastic abatement measures (Wigley 2006). However, SAI research is still in a nascent state, and our understanding about the potential impacts of SAI is limited. The following two sections outline the current state of research in natural sciences and in social sciences and humanities on the environmental as well as the social, political, and ethical risks of SAI, and the uncertainties around these risks.

3.2 SAI from the Perspective of Natural Sciences: Potential Benefits, Risks, and Uncertainty

3.2.1 Uncertainty around the Effectiveness of SAI

Climate change is a complex problem pertaining to a complex natural system which is in constant interaction with other complex systems, both natural and human. As a proposed solution, SAI research and deployment would have to work through this compound complexity, taking into account the many possible direct impacts of SAI as well as its indirect impacts and possible feedback mechanisms. Current scientific knowledge is far from achieving this. There are many uncertainties and knowledge gaps about the effectiveness and the risks of SAI.

Available research suggests that climate geoengineering strategies can achieve considerable decreases in surface temperatures as well as the occurrence of extreme weather events (Irvine et al. 2019; National Academies of Sciences and Medicine 2021). However, there are many factors that would affect the amount of cooling such as on changes in the large-scale dynamics of the stratosphere (Kleinschmitt, Boucher, and Platt 2018; Marshall et al. 2019), the geographical location (Tilmes et al. 2017; Tilmes, Richter, Mills, Kravitz, MacMartin, Garcia, Kinnison, Lamarque, Tribbia, and Vitt 2018) and season of deployment (Visioni et al. 2019), and the amount and type of material that would be injected (National Academies of Sciences and Medicine 2021). Current scientific knowledge on these factors is very limited.

There is also uncertainty about the maximum rate of cooling that can be achieved by SAI. Many studies show that the relationship between the amount of sulfur that is injected in the atmosphere and the amount of cooling is a non-linear one. That is, as the amount of sulfur which is already in the atmosphere increases, the cooling effect of additional sulfur decreases. However, scholars disagree about the nature of this non-linear relationship which ultimately determines the maximum amount of cooling that SAI can bring about (Kleinschmitt, Boucher, and Platt 2018; Kravitz, MacMartin, Tilmes, Richter, Mills, Lamarque, Tribbia, and Large 2019; Niemeier and Timmreck 2015). Most natural science research on SAI is based on idealized climate models. As explained in the first chapter, these models are inherently uncertain. They cannot represent all relevant aspects of natural systems with high accuracy. This is true also for SAI models. SAI models have limited capacity in representing the complex physical and chemical processes, interactions and feedback mechanisms through which SAI impacts will occur (Simpson et al.

2019). Many key factors that determine the impacts of SAI are shaped at the microphysical level which cannot be adequately represented by SAI models. To illustrate, let us briefly explain the phenomenon of *stratospheric heating* related to SAI. Besides reflecting incoming solar radiation, sulphates also absorb some of the outgoing infrared radiation. This results in heating and increased amount of water in the stratosphere. This increase in water vapor in turn will affect radiation and may offset some of the cooling achieved with SAI (Krishnamohan et al. 2019; Tilmes, Richter, Kravitz, MacMartin, Mills, Simpson, Glanville, Fasullo, Phillips, and Lamarque 2018). Stratospheric heating will limit the effectiveness of SAI. The amount of this heating is mainly determined by the size distribution of aerosols in the stratosphere, which in turn is formed through microphysical processes.

Microphysical processes correspond to a scale that is much smaller than a grid cell of a climate model. That is why they are not adequately represented in these models. In fact, until recently, SAI models did not include microphysical processes at all. Rather, they worked by simply "dimming the sunlight", and assuming that this dimming could be achieved by a given amount of aerosol injection (Kravitz et al. 2011). In recent years, more simulations start with the injection of sulfur dioxide and include the microphysical processes, then calculate the resulting decrease in solar radiation and the cooling effect accordingly (Kravitz et al. 2017; Kravitz, MacMartin, Tilmes, Richter, Mills, Cheng, Dagon, Glanville, Lamarque, and Simpson 2019; Mills et al. 2017; Tilmes, Richter, Kravitz, MacMartin, Mills, Simpson, Glanville, Fasullo, Phillips, and Lamarque 2018). However, they still cannot capture these processes with high accuracy, but use parameters to represent them in a simplified fashion. Currently, there is disagreement between different models on the amount of stratospheric heating due to their differences in microphysical parameterizations (National Academies of Sciences and Medicine 2021).

Besides idealized models, observational studies of volcanic eruptions can provide us with many important insights on SAI. However, they are also an imperfect analogue for SAI. First, the timescale of a possible SAI deployment would be very different from that of a volcano eruption. Volcano eruptions are one-time events, and their effects wear off in a few years. However, SAI will be deployed continuously and deliberatively to achieve a decades-long effect. It is difficult to extrapolate the effects of SAI from those of volcano eruptions. Secondly, while volcano eruptions mainly emit sulfur to the atmosphere, SAI may involve alternative materials such as calcites to evade some of the side effects of sulfur. These materials do not have natural proxies, therefore observational studies do not help us in understanding their properties (National Academies of Sciences and Medicine 2021).

Another way to learn about the impacts of SAI would be field experiments. Some researchers assert that we should already move on to small-scale field experiments to advance our understanding of SAI. However, other scientists argue that small-scale research cannot provide us with much valuable information on the impacts of actual deployment, again due to difficulties in extrapolation. Some scholars even argue that SAI cannot ever be properly tested. This is because the only reliable way to learn about the potential impacts of SAI would be large-scale field tests which would amount to actual deployment (Robock et al. 2010).

3.2.2 Regional and Seasonal Climatic Changes

Even though the cooling effect of SAI will be global, there will be important variations in regional and seasonal climate impacts of SAI depending on how SAI is deployed, specifically choices about latitude and the material that is used. For example, climate models suggest that equatorial deployment would result in over-cooling of tropical regions and under-cooling of polar regions (Kravitz et al. 2017; Kravitz, MacMartin, Tilmes, Richter, Mills, Lamarque, Tribbia, and Large 2019; Tilmes, Richter, Kravitz, MacMartin, Mills, Simpson, Glanville, Fasullo, Phillips, and Lamarque 2018). Deployment at other locations could compensate these effects but would create other regional disparities.

Many models estimate that global average precipitation will decline with SAI deployment (Cheng et al. 2019; Simpson et al. 2019; Tilmes et al. 2013). SAI could also alter regional precipitation and evaporation patterns (Irvine, Ridgwell, and Lunt 2010; Matthews and Caldeira 2007; Robock, Oman, and Stenchikov 2008). This phenomenon was observed in the wake of the Mt. Pinatubo eruption which resulted in decreased rainfall and droughts in some regions (Trenberth and Dai 2007). Some studies imply that important changes will happen to precipitation in the Sahel region of Africa to the Indian and Asian monsoons (National Academies of Sciences and Medicine 2021). Such changes in temperatures and precipitation could harm people by risking their food and water supplies, especially if they occur in vulnerable regions (Robock, Oman, and Stenchikov 2008). In current climate models, there is a high level of uncertainty in the details of these regional disparities.

Finally, seasonal variations also seem to be significant. SAI decreases the difference between seasonal temperatures at high latitudes, resulting in cooler summers and warmer winters (Tilmes, Richter, Kravitz, MacMartin, Mills, Simpson, Glanville, Fasullo, Phillips, and Lamarque 2018). These changes would greatly affect the seasonal cycles of snow depth and sea ice (Jiang et al. 2019). These changes would have critical implications for human communities whose livelihood depends on these seasonal cycles. However, at the moment there is no available research on this topic.

3.2.3 Termination Shock

Probably the most serious risk from SAI is called termination shock in the literature. Termination shock is that if, for some reason, deployment had to suddenly be halted, temperatures would very rapidly -in a few years- return to what they would be if there had been no SAI deployment, unless GHG emissions were not dramatically reduced (Robock et al. 2010). Warming would be so rapid because of the short lifespan of aerosols in the stratosphere. This rapid rise in temperatures would have catastrophic consequences for ecosystems and humans (Goes, Tuana, and Keller 2011).

3.2.4 Ocean Acidification

Ocean acidification happens when the amount of CO_2 absorbed by the oceans increases. It harms marine ecosystems, particularly coral reefs by impairing their ability to form shells. It also negatively affects coastal human communities whose income depends on economic activities related to coral reefs such as fisheries and tourism (Doney et al. 2009; Hoegh-Guldberg et al. 2007). Because SRM allows CO_2 concentrations to keep on rising, the problem of ocean acidification will be left unaddressed. Moreover, SAI may slightly increase ocean acidification because lowered ambient temperatures increase the solution rate of CO_2 in waters (National Academies of Sciences and Medicine 2021).

3.2.5 Stratospheric Ozone Loss

Another important risk of SAI is stratospheric ozone depletion. SAI is expected to cause ozone depletion through two mechanisms. First, changes in stratospheric circulation due to stratospheric warming explained above will also affect the transport and distribution of ozone in the stratosphere. Secondly, sulfates trigger chemical reactions that alter the concentration of compounds that cause ozone loss (Klobas et al. 2017; Tilmes et al. 2020). While there are many uncertainties around the magnitude and even the sign of regional ozone changes, it is estimated that SAI using sulfates would delay the recovery of the Antarctic ozone hole (Pitari et al. 2014). SAI using alternative materials such as calcites, alumina, and rutile have been proposed to evade ozone depletion. Simulation studies of these materials suggest that they can minimize stratospheric warming and ozone loss while also cooling the planet. However, the microphysical properties of these materials are poorly understood (Dykema, Keith, and Keutsch 2016; Keith et al. 2016). Therefore, their possible large-scale effects are unknown (Fahey et al. 2018). Ozone depletion would increase the amount of ultraviolet radiation that reaches Earth's surface, with negative impacts to human health and ecosystems.

3.2.6 Decrease in Direct Light

Besides reflecting some portion of sunlight back into the space, SAI will also have the effect of scattering the sunlight that reaches the surface. This will result in an increased diffuse light/direct light ratio (Kravitz, MacMartin, and Caldeira 2012; Madronich et al. 2018; Xia et al. 2016). Besides making our skies whiter, this increase in diffuse light will impact plant growth and solar energy production. Diffuse light can increase photosynthesis and increase the global food supply (Mercado et al. 2009). However, crop production depends on many other factors such as temperature, precipitation and atmospheric CO_2 levels, crop characteristics, and farming techniques. That is why estimates vary considerably with increases for some crops and regions and decreases for others (Yang et al. 2016). Dispersed light can also reduce solar energy production depending on the method that is used. For concentrating solar power methods which use direct sunlight, there can be substantial decreases, while photovoltaic solar energy systems will be less affected since they can also use diffuse sunlight (Smith et al. 2017).

3.3 Social, Political, Ethical Risks

3.3.1 Moral Hazard and Moral Corruption

Moral hazard is a term borrowed from insurance industry, and originally refers to the increased inclination of people who have insurance to engage in risky behavior. Within the context of SAI, it refers to the idea that mere contemplation of the prospects of SAI decreases the incentive to undertake abatement and adaptation (Hale 2012; Lin 2013). In other words, even before engaging in serious SAI research, let alone deployment, the idea that such a technical fix can possibly come to being in the future can create false hope among people, especially among politicians and corporate actors, and give them further incentives to shirk from costly climate action. The risk of moral hazard is increased by what Gardiner calls "intergenerational buck passing" which is at the root of current inertia in climate politics. According to Gardiner, current generations have the temptation to defer abatement because while the costs of abatement would be assumed by them, many of its benefits would arise only for the future generations due to the lagged nature of the climate system (Gardiner 2011). Even advocates of SAI research acknowledge this risk, and make calls for decisive emission reductions (Keith, Parson, and Morgan 2010).

Whether moral hazard will occur and if so, to what extent, is a question that should be empirically assessed (Lin 2013). An alternative view is that prospects of SAI will have the opposite effect. That is, by realization that they may one day have to live under an engineered sky may galvanize people do what it takes to avoid this future. According to Gardiner, however, this is a weak possibility. It is not likely that decades of inertia will wither away just because SAI becomes an option on the table (Gardiner 2011). Gardiner believes that there is a deeper ethical problem behind this moral hazard related to SAI, which he calls a moral corruption. He defines moral corruption as "subversion of our moral discourse to our own ends" (Gardiner 2010). Rich nations are the main responsible of climate change. Yet, instead of assuming their responsibility by pursuing decisive abatement and adaptation strategies, they try to shirk from it by considering SAI as an acceptable solution to climate change, and even framing it as a moral duty towards the global poor, the future people, and the nature. Because SAI is a speculative technology with a plethora of risks, presenting SAI as a viable option is willful self-deception, and is a type of moral corruption (Gardiner 2011).

3.3.2 Language of SAI: Terminology and Framing

The risk of moral hazard may be augmented based on the language that commentators adopt. To begin with, the very terms that we use for this new technology may have subtle meanings. For instance, the words "engineering" in Climate Geoengineering and "management" in Solar Radiation Management have been scrutinized by some scholars as evoking a false sense of accuracy and predictability, which is far from how the current proposals are. With this concern in mind, alternative terms have been proposed to replace "solar radiation management", such as "sunlight reflection methods" which has the same initials (Elliott 2016). Authors of the

2015 US National Academy of Sciences report opted for the term "climate intervention" instead of "climate geoengineering", and "albedo modification" instead of solar radiation management to avoid such misleading connotations (National Research Council 2015*b*). However, another National Academy of Sciences report published recently chose "solar geoengineering" to designate SRM (National Academies of Sciences and Medicine 2021). One of the authors of the 2015 report even proposed "albedo hacking" as a term for SAI to highlight its risky nature (Pierrehumbert 2015).

The frames that are being used in SAI discussions may also affect the risk of moral hazard. One common framing of SAI is "technological fix". The term "technological fix" refers to technical solutions to complicated social problems which would other require deep transformations in behaviors (Weinberg 1967). Technological solutions may seem preferable as easy, quick, and less demanding solutions when it has proved very difficult to bring about the necessary behavioral changes. However, the term technological fix, especially in its shortened from "techno-fix", has a derogatory connotation of superficial, complacent solutions to deep problems. Given our decades-long failure to decrease GHG emissions and SAI's promotion by its advocates as an "effective, technically feasible, inexpensive, rapid, [and] reversible" (Reynolds and Horton 2020) method to reduce climate change, SAI seems to perfectly fit the technological fix framework (Scott 2012). This way, SAI may be perceived by some as a magic bullet allowing us to continue our destructive habits of overconsumption and burning of fossil fuels. Moreover, this framing may conceal the myriad of risks that would accompany both the research and deployment of SAI and divert our attention from other strategies while they are still feasible.

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the myriad of risks that would accompany both the research and deployment of SAI and divert our attention from other strategies while they are still feasible.

Another framing of SAI is the “plan B” frame (Morgan and Ricke 2010). According to this framework, SAI should be developed as an insurance in case we are faced with a climate emergency (Keith, Parson, and Morgan 2010). While the “plan B” frame acknowledges that SAI will be used as a last resort, and reducing emissions should be the priority, it is still problematic. First, words such as “insurance” or “plan B” cause the same problem explained in the above paragraph: they present SAI as “embodying a mature and cautious wisdom (Preston 2013).” Second, it is not obvious what counts as a climate emergency, how we would recognize it, and how it would be declared. For instance, what holds us back from declaring a climate emergency now, when many vulnerable populations are already being devastated by floods or droughts (Tuana et al. 2012)? Moreover, due to the lagged nature of climate, it may be too late to take action when we observe those events that would indicate a climate threshold response. Third, emergency discourses are often used spread fear with an aim to justify otherwise controversial, unjust decisions. Given the willingness of many political and corporate actors to postpone emission reductions, this risk is of serious concern (Gardiner 2010; Sillmann et al. 2015).

3.3.3 Slippery Slope and Sociotechnical Lock-in

The idea of *lock-in* or *path dependency* refers to the tendency of expensive emerging technologies to be implemented ultimately even though they are not sufficiently effective or safe. This happens because the research and development of these technologies involve investors, institutions, and experts who invest money, time, and effort in SAI, building up vested interests around that technology (Ott 2012). These institutions and people work as an interest group such that it becomes increasingly difficult to stop the advance of that technology as more time and money is invested in it. The pressure from vested interests in SAI research may result in the premature deployment of the technology without sufficient knowledge about its risks and before just governance mechanisms are in place (Hourdequin 2012; Jamieson 1996). Such path dependence may also inhibit the consideration of other feasible options (Cairns 2014). Even early results in SAI research which are promising may create a momentum which would lead us down a *slippery slope* toward deployment (Ott 2012). Moreover, if GHG concentrations continue to mount up while we use SAI, we may have to commit to deploying SAI for centuries without interruption, and with increased intensity while trying to strike a balance between increased GHG concentrations and decreased solar radiation (McKinnon 2019). It is unrealistic to expect that humanity can successfully sustain this balance, and failure to do so would result in the catastrophic termination shock.

3.3.4 International Relations

Prospects of SAI raise concerns of conflict on the international scene. These concerns are often invoked by the question "whose hands will be on the thermostat?". Countries who developed SAI capabilities would have excessive power, since they would be able to control the global climate. Hence, SAI has the potential risk to destabilize international relations. Because SAI would be relatively inexpensive, there is the risk of unilateral deployment by a single country or even a wealthy enough private actor (Victor et al. 2009). Any SAI deployment that will produce sufficient cooling at the global scale will be easy to detect with available monitoring instruments. Therefore, the risk of rogue deployments going undetected is very low (National Academies of Sciences and Medicine 2021). However, due to the variable effects of SAI on different regions, a state may inadvertently harm other states while trying to counteract adverse weather conditions in its own country (Barrett 2008). In this case, detection of transboundary harms will be very difficult if not impossible. Because of the inherent complexity of the climate system, it will be very difficult to attribute a hurricane, a drought, or any other harmful weather event to SAI activities, climate change, or natural climate variability (Robock 2012). Therefore, liability and compensation claims will be very difficult to make (National Academies of Sciences and Medicine 2021).

Even if we assumed that the transboundary harms from SAI could be accurately detected and compensated, SAI could still raise international conflicts. This is because some countries may be better off under particular climate strategies. The preference of countries on whether and how SAI should be deployed will depend on the regional climate outcomes that is optimal for them (Morgan and Ricke 2010). In other words, international SAI bargaining will not only be about avoiding harms, but also about achieving net gains. Some countries may even use SAI to create "designer climates" which are radically different than their pre-industrial climates, with an aim to reap economic benefits. For instance, Canadians may prefer an ice-free Northwest Passage to facilitate trade. Russians may desire a warmer Siberia to expand their arable lands. Parts of Africa may want increased rainfall (Preston 2013). Since it may not be possible to address all these preferences at once, any decision to deploy SAI is prone to be conflict-ridden.

3.3.5 Justice

The effects of both climate change and SAI would be unevenly spread around the globe. Hence, choices about whether and how to pursue SAI have implications for distributive justice at a global scale. Some authors have argued that conducting SAI research is a moral duty, since this technology could potentially alleviate some existing injustices to the "global poor" caused by the climate change (Horton and Keith 2016). However, others contend that SAI would go against global justice because if deployed, the worst side effects of SAI would likely be experienced by this same global poor, the people living in the Southern hemisphere who have the least capacity to adapt to climate risks (Preston 2012). This injustice would be compounded by the fact that the global poor are also the people who have done the least in creating climate change (Svoboda et al. 2011).

Since climate change is a long-term problem spanning several generations, any solution that is proposed would also have implications for intergenerational justice. Some argue that researching SAI now upholds intergenerational justice since it will provide the future generations with an additional strategy that they may employ in case abatement efforts prove insufficient (Cicerone 2006). Others argue that using SAI in accordance with the principles of intergenerational justice would be difficult (Burns 2011). Instead of distracting ourselves with speculative ideas on risky technologies, intergenerational justice demands that we, as the current generation, focus on our moral duty to take drastic abatement measures so that future generations will never have to use such risky technologies (Gardiner 2010). The decision to initiate SAI deployment would lock future generations in a centuries-long commitment in case GHG emissions are left to rise due to moral hazard (McKinnon 2019). Considering the risk of a slippery slope from research to deployment, our generation may even be sealing this commitment right now by choosing to advance research. Making such a grand commitment in the name of people who are not yet born, and condemning them to the fatal risk of termination shock in case they could not fulfill this commitment goes against intergenerational justice (Gardiner 2010, 2011). At the intersection of slippery slope, path dependence, moral hazard, and termination shock lies injustice. Finally, Republican view argues that even if its adverse environmental effects could be avoided, deciding to deploy SAI as a primary strategy would be unjust because it would yield an arbitrary power on future people, deepening their domination by the present people (Smith 2012).

SAI research and deployment also has implications for ecological justice. Potential risks of SAI such as changes in temperature and precipitation patterns, continuing ocean acidification, and increased ultraviolet radiation can pose serious threats for non-human species. Especially, termination shock would have catastrophic consequences for many living organisms (Sandler 2012). Climate change is already violating ecological justice by leading to the extinction of many species. Some species may survive by adapting to the changes or migrating to cooler regions. However, abrupt changes in temperatures in case of termination shock would drastically decrease the chances of such behavior, even for the most mobile or resilient species (Chen et al. 2011).

3.4 Discussion

If research into SAI continues, this technology may one day prove to be an effective and safe way to alleviate climate change. Alternatively, it may prove to be an ineffective method which can then be ruled out. This is main argument in favor of SAI research. There is one serious problem with this argument, though. Namely, it assumes that by the time when we may want to consider using SAI, our knowledge of it will have reached a sufficient level to help us with a verdict for or against its usage. This assumption may not hold. Climate system is inherently chaotic, findings from computer models are still too vague, and our time is running out. At that unfortunate moment, it is highly likely that the decision-makers will not know enough to make the decision in an informed and reasonable way: to deploy or not to deploy?

Worse, decision-makers may think that they know enough about SAI when in fact they do not. Guided by the scientists, they may choose to authorize the deployment of SAI in a specific way, with the false belief that it will effectively cool the planet and will do so in a safe enough way. Even before that, they may give license to large-scale outdoor experiments, believing that there will be no serious harms. Why would scientists misguide the decision-makers? They would not do so intentionally. I personally believe that scientists who are working on SAI are in good faith and that they want to help tackle climate change. However, the discussion in the first chapter showed us that epistemic risks in science – i.e., those risks related to decision-making in scientific practice under uncertainty, which may result in false knowledge, are often due to implicit background assumptions and value judgments that scientists may not even be aware of. In all scientific research, there are some decisions to take without full knowledge. Being an evidence-based activity, this is inherent to science: evidence is never conclusive. There are no definite ways to pose a research question, formulate hypotheses, build up a research design, categorize and interpret data, and conduct hypothesis testing. At each of these steps, scientists have to choose one option over others. These choices are made based on value judgments about the consequences of being wrong for each possible option.

While decisions under uncertainty exist in all research areas, in SAI research they are all the more difficult to make and consequential. Given the complex nature of the climate system, computer models of SAI still yield very uncertain findings. Decisions have to be made about which aspects of the climate will be given more weight in the model. Those prioritized aspects will be predicted with increased accuracy, and other aspects with decreased accuracy. These decisions require value judgments about which aspects are more important to know. Regarding SAI, there is scant knowledge about the complex physical and chemical processes behind the cooling effect of aerosols. These micro-level processes have to be estimated and parametrized before being built into models. Assumptions have to be made when dealing with these parametrizations which once again require value-laden decisions. An SAI researcher may desire to discover that SAI is an effective and safe method and may wish to see it deployed soon. Different motivations may be fueling this desire: career, prestige, concerns with climate change, or even sheer curiosity. That is why, when making these uncertain modelling decisions, the SAI researcher may be -knowingly or unknowingly- more optimistic about the prospects of SAI in terms of its effectiveness and safety, compared to an average person or more importantly to a person who is living in a region highly vulnerable to climate impacts. Therefore, she may be more willing than the lay people to take all the subtle epistemic risks on her way to the conclusion that SAI is a plausible climate strategy. This is how the scientist may mislead the decision-maker: By taking undue epistemic risks in the research process which will end up being the knowledge basis of SAI policies.

The physical risks of SAI are compounded by its social risks. Undue optimism about the prospects of SAI may lead to moral hazard, making decision-makers in economic and political spheres to loosen efforts in other climate strategies, only to discover that SAI is not a feasible option after years of research. Alternatively, if SAI is found to be feasible and starts to be deployed, this is still not good enough news. Again, moral hazard may result in higher GHG concentrations, with the looming risk of termination shock.

Given all these risks and uncertainties, and of course the possible benefits, should SAI research continue? One person might conclude that a moratorium on SAI research may seem like the right thing to do: Researching into SAI cannot possibly provide us with a sufficient knowledge basis for a plausible deployment scenario by the time we may need it. Also considering the risk of a slippery slope from research to deployment, we would better stop research early on to decisively avoid any harms which may result from irresponsible deployment. Another person may acknowledge the risks, yet still may advocate for continuing the research: Given the slow pace of emissions reductions, we may once day desperately need the technology to curb the increase in temperatures, despite its many risks. In fact, the only way to learn more about and alleviate these risks is to do more research.

Instead of individual answers to these questions regarding SAI research and deployment, it is crucial to come to a collective verdict on SAI. According to the *democracy* argument introduced in Chapter 1, our commitment to democratic principles require that the public has due influence on decisions in science and technology which are value-laden and affect people considerably. Value-laden decisions are ubiquitous at all steps of actual and potential SAI-related activities, and they will have fateful consequences for literally the whole global population. These decisions should not be settled by a handful of scientists, politicians, and corporate actors, whose values may not align with the social needs and priorities. Mechanisms should be designed and established through which the “global public” can have a meaningful influence in decisions regarding SAI research and deployment.

Besides the democracy argument, the two auxiliary arguments which I call *sound science* and *public trust* arguments are also relevant for public participation in SAI. According to the sound science argument, public participation in science can enhance the reliability of scientific knowledge by scrutinizing illegitimate value influences and by contributing to science with lay knowledge. Firstly, most of the current SAI research is conducted by a narrow expert community which lacks diversity (Buck, Gammon, and Preston 2014; Winickoff, Flegal, and Asrat 2015). While there are efforts such as the DECIMALS fund to increase representation of the global south in SAI research community (Solar Radiation Management Governance Initiative (SRMGI) N.d.), this will not be sufficient to ensure that research is influenced by the right values. The reason is that as explained in the first chapter, scientists' interests and priorities may differ from those of the general public. Public participation is a more robust way to ensure that social and ethical values are taken into account in research, which will enhance reliability of scientific as knowledge as well as democracy. Second, traditional ecological knowledge of indigenous populations which have inhabited a certain geography since centuries may be used to improve scientific knowledge on climate change as well as on SAI.

According to the *public trust* argument, public participation -if designed properly- can foster public trust in science by improving public understanding of science and changing the relationship between the scientists and the public. The current landscape of public trust in climate science as well as SAI is bleak. Besides the climate denialist movements described in the first chapter, there is also a burgeoning conspiracy theory about SAI called Chemtrails according to which toxic chemicals for weather manipulation and for mind control are being sprayed by airplanes through contrails (Tingley and Wagner 2017). Public participation in SAI science may be used to counter such conspiracies by engaging the scientists and the people in a dialogue. On the one hand, scientists will have the opportunity to communicate the key findings of SAI science as well as the uncertainties around these findings which will increase public understanding of science. On the other hand, the public will have the chance to express their beliefs, preferences, and concerns to scientists and decision-makers. A properly designed participation exercise would make sure that these views are adequately included in decision-making. Consequently, public trust in science would be enhanced since people would know that their voices were heard. In contrast, moving forward with SAI research and possible deployment without public participation would only exacerbate suspicions and further decrease public trust in science.

4. CHAPTER 3 PUBLIC PARTICIPATION IN SAI: PROPOSAL FOR A GLOBAL CITIZENS ASSEMBLY

In the first two chapters, I discussed why democratic participation in science and technology issues, particularly in SAI, is necessary. To summarize, there are value-laden decisions in all stages of science. Setting of the research agenda, allocation of funding to different projects, background assumptions in formulating research questions and hypotheses, modelling choices, epistemic risks regarding research design and hypothesis testing, implementation of findings, and framing and terminology all involve value-laden decisions. I argued for comprehensive public engagement. That is, value-laden decisions in all stages of science should be guided by social and moral values through public participation. Since these decisions end up affecting the lives of many people in a myriad of ways, they cannot be left to the discretion of scientists and their sponsors.

One might argue that scientific knowledge, by itself, does not have tangible impacts on people. It can only affect people through implementation, usually in the form of a new technology. Therefore, it suffices to restrict public participation to the last stage, translation of "pure" scientific knowledge to technological artefacts which work on the physical world. I oppose to this argument. Contrary to the popular view, science and technology are not distinct processes. The shape of a prospective technology is determined by the scientific knowledge that is already available which in turn is determined by a chain of earlier choices on research areas, questions, and designs. Usually, scientific research is conducted with a clear technological application in mind. Path dependency and slippery slope are a direct result of this fact. Moreover, it is not that science ends where technology starts. On the contrary, scientific research and technological usage are in a constant mutual feedback. In short, science and technology are inseparable processes in many cases. Effective democratization of a technology requires comprehensive public engagement from the very beginning, in both scientific and technological phases.

While the need for democratic participation into SAI research is clear, it is not obvious what kind of a democracy this participation should be based upon. In theoretical terms, which model of democracy would best achieve the goal of "meaningful public influence" in decisions related to science and technology? In practical terms, what kind of public participation mechanisms have already been devised and tested which conform to this specific model of democracy? In this chapter, I aim to answer these questions. In the first section, I argue that public participation in SAI entails democratic participation that is *informed, deliberative, globally representative, comprehensive, and legitimate.* Here, I draw on three distinct lines of thought: Kitcher's well-ordered science, deliberative democracy, and global democracy. In the second and third sections, I review how public participation in science has fared so far with a special focus on deliberative mini-publics. I conclude the chapter by arguing that an issue-specific Global Citizens' Assembly would be the most adequate forum to realize public participation in SAI.

4.1 Which Democracy? A Theoretical Inquiry

4.1.1 Well-Ordered Science

Philip Kitcher's theory of well-ordered science (Kitcher 2001, 2011) is a good starting point to conceive a model of democracy that is suitable for public participation in SAI. Being a philosopher of science, Kitcher sees the current relationship between scientific expertise and democracy as problematic. To reflect on the proper relationship, he develops an ideal account of how science should be organized in a democratic society and begins by positing proper conceptions of both science and democracy.

Kitcher's conception of science aligns with the conception presented in chapter 1. Science is not a value-free activity. All stages of scientific activity involve moments where value-laden decisions need to be taken. The idea of an autonomous science is a residue of earlier periods when democracy was not established and when science was mainly conducted by private individuals for their own curiosity, without considerable impact on public life. However, times have changed. Science has become a powerful institution which affects people's lives in myriad ways, and societies have adopted democratic principles according to which people should have a say in decisions that affect them. It may be that scientists have a good estimate about the broad consequences of the research they pursue now. However, they cannot possibly know what the specific consequences will be for all the individuals which will be affected by that research, even if they intended to do so. Individual people are the best judges of their own predicament. In a sense, they are the "experts" of their own lives. Under these circumstances, democratic participation in science is essential for people to protect their interests. We should reform our current institutions which govern scientific activities so that they better serve the collective good (Kitcher 2011).

What kind of democratic influence on science is acceptable? According to Kitcher, only informed opinions of the people can legitimately guide scientific activity. Trying to evade technocracy, it is important not to fall into the trap of tyranny of ignorance. Voting on scientific issues without due information would amount only to a "vulgar" form of democracy. Therefore, we need a more sophisticated democratic mechanism which would allow making informed public decisions on science (Kitcher 2001, 117).

To articulate such a mechanism, Kitcher envisages a hypothetical deliberation involving experts and lay members of the society who represent diverse views. The aim of this deliberation is to arrive at three decisions concerning science policy: allocation of resources to particular research projects, designating moral constraints on research methods, and translation of research findings into applications. Each decision is deliberated on one by one. Kitcher illustrates the deliberation for the first decision, the one made for the allocation of resources, as follows: In the first step, the citizen deliberators go through a *tutoring* phase where they learn about the current state of science. They hear from a diverse range of experts who explain why and how they think particular areas of research are significant and should be further pursued. The second step involves *deliberation* among citizens themselves, in which each deliberator shares her personal views, interests, and preferences -now informed thanks to tutoring- with the other deliberators. Through mutual consideration of diverse preferences, a list of collective preferences is agreed upon. Third, citizens consult the experts once again. This time, experts are *deferred* to for an assessment of particular research projects in terms of their possibility to yield outcomes that will satisfy the collective preferences. In the fourth step, an *arbitrator* formulates plans for possible resource allocations. These plans are based on the collective citizen preferences and the probabilities of research projects for satisfying these preferences, assigned by the experts. They also conform with the moral restraints on research determined by the citizens. The moral restraints have been decided upon in a separate deliberation, reconciliating different conceptions of rights and moral principles adopted by different members of the society. These restraints correspond to procedural ethics which is concerned with avoiding harms that are immediately related to the research process – e.g., the proper treatment of human and non-human experimental subjects. Finally, in the fifth step, citizen deliberators make a *judgment* to agree upon one of the plans proposed by the arbitrator. A similar deliberation takes place after the research projects are concluded to decide upon how to translate the research results into practice. Even though the initial decision for allocation of resources has been made with practical outcomes in mind, reiterating deliberation after research is necessary to be able to account for updated knowledge which in turn can lead to a revision of preferences (Kitcher 2001, 118-122).

Based on the hypothetical deliberation outlined above, Kitcher builds an ideal of science in a democratic society, called well-ordered science.

> "For perfectly well-ordered science we require that there be institutions governing the practice of inquiry within the society that invariably lead to investigations that coincide in three respects with the judgments of ideal deliberators, representative of the distribution of viewpoints in the society. First, at the stage of agenda-setting, the assignment of resources to projects is exactly the one that would be chosen though the process of ideal deliberation I have described. Second, in the pursuit of the investigations, the strategies adopted are those which are maximally efficient among the set that accords with the moral constraints the ideal deliberators would collectively choose. Third, in the translation of results of inquiry into applications, the policy followed is just the one that would be recommended by ideal deliberators who underwent the process described (Kitcher 2001, 122-123)"

As seen above, in his 2001 book *Science, Truth, and Democracy*, Kitcher argues that social preferences should influence scientific inquiry in three instances: agenda-setting, ethical oversight, and implementation. In chapter 1, I explain that the internal processes of scientific activity involve many value-laden decisions, and that these are not limited to decisions about procedural ethics. To recall, many choices regarding research design and methodology involved epistemic risks and thus were value-laden. In his 2011 book, *Science in a Democratic Society*, Kitcher extends his ideal of well-ordered science to comprise such decisions as well. Specifically, he elaborates on the *certification* stage of science – i.e., the stage in which a scientific finding is admitted or rejected as part of public knowledge. For this, a decision should be made which certifies the finding as both sufficiently true and important. Typically, each scientific discipline has methodological guidelines to that end. These guidelines are reliable as long as they generate conclusions that are" true *enough*, at a frequency that is high *enough*." (Kitcher 2011, 147). Obviously, these decisions about the sufficient levels of importance, proximity to truth, and frequency of being close to truth are value-laden decisions. According to Kitcher, values of the public should guide the formulation of these research guidelines, along with the best-known practices in a given area. As discussed in chapter 1, internal processes of science usually do well in weeding out individual misconducts in the context of certification. However, there is one worry that persists: scientific community may have a pervasive bias towards overlooking certain types of questions or may have evidential standards which are not in harmony with social values. The context of certification would be well-ordered when the level of sufficiency of "proximity to truth and of probability of generating truth" should approximate those levels that would be decided on in an ideal deliberation. Being informed about the current procedures and standards used in a given area of scientific research, the ideal deliberators estimate the consequences of choosing a particular set of procedures and standards in this area to the best of their ability. Through engagement with diverse views on the acceptability of these consequences, they collectively endorse specific sets of methodological guidelines for each area of research which will be the basis of certification (Kitcher 2011, 145-151).

Kitcher's extension of the ideal to the contexts of science other than investigation connects back to the argument from inductive risk (Douglas 2009; Rudner 1953). The extended ideal of well-ordered science gives support to the idea that values of the public should guide science not only at the initial stage of setting research priorities, but also during research itself (indirectly) by helping to set evidentiary standards in hypothesis testing (Irzık and Kurtulmuş 2018). Other epistemic risks related with formulation of research questions, choice of hypotheses and variables, data operationalizations, and so on, can also be scrutinized by the ideal deliberators while formulating methodological guidelines. Because these choices considerably affect the research outcomes being "true enough", the public has a right to guide them.

Even if certification is well-ordered, democracy cannot function well unless the broader public recognizes it as such. Here, another ideal, transparency, becomes relevant. According to Kitcher, a system of public knowledge is ideally transparent when all people can fully see, understand, and accept the ways in which certification is effectuated. When both ideals (well-ordered science and ideal transparency) hold, the system of public knowledge ideally promotes collective good, people acknowledge this and trust the authority of science (Kitcher 2011, 149).

Who are the ideal deliberators? Since science affects all present and future human beings, all the alternative perspectives of humans should be included in the conversation, including the unborn. While the perspectives of future people cannot be known with any precision, they can be explored in deliberation through sympathy. It would not be too speculative to suggest that our grandchildren would wish to live on a habitable planet, for instance. Therefore, Kitcher thinks the ideal of well-ordered science as a panhuman conversation and rejects any narrowing down of the conservation to a smaller group, such as a nation or the present people, on ethical grounds (Kitcher 2011, 114-116).

Critiques of Kitcher have argued that due to its hypothetical character, the ideal of well-ordered science cannot provide us with substantial guidance. Simply put, we cannot possibly know the outcomes of a deliberation which have never occurred and will never occur (Brown 2013; Douglas 2013). Kitcher acknowledges that well-ordered science in its perfect form is an unapproachable ideal. There are many practical constraints in engaging citizens in a deliberation process at the global scale, one that involves full information on scientific issues and that includes virtually all viewpoints in a society. Still, Kitcher argues that the ideal can be approximated by promoting informed citizen involvement, possibly using innovative deliberative mechanisms such as citizens' juries and deliberative polls.[1] As for ideal transparency, it can be approximated by increasing scientific literacy within the society, besides making research results publicly accessible. Since ideal transparency requires that people can not only see but also understand the ways in which research results are validated, their grasp of scientific methods and outcomes should be sufficiently improved for approaching this ideal.

In the next two sub-sections, I briefly touch upon theories of deliberative democracy and global democracy in turn, with an aim to ground Kitcher's ideal of "panhuman conversation" in political theory. What exactly does deliberation mean, and how does it connect to democracy? How would a deliberation process that is representative of all geographic and demographic groups, one that is "globally representative", enhance democracy in international governance? Answering these questions at a theoretical level will help us further in formulating criteria for assessing extant public participation mechanisms in terms of their adequacy for SAI.

4.1.2 Deliberative Democracy

Deliberative democracy is a model of democracy that has gained prominence especially since the 1980s. It is based on the idea that political decisions

[1]These mechanisms will be discussed later in section 3 of this chapter.

in a democratic society should be based on fair and reasonable discussion among its members, namely deliberation (Habermas 1984; Mansbridge 1983). In the deliberative ideal, citizens come together and discuss on issues of common concern based on equal recognition and respect, then decide together on these issues. All parties present reasons for their claims and listen to each other's claims and reasons carefully. The deliberation reflects the diversity of values, interests, and experiences within a democratic society. After weighing competing reasons against one another and evaluating them on their merits, the deliberants make a collective decision. This may be a consensus decision, or a majority decision which acknowledges minority views. Essentially, deliberative democracy places reasonable communication at the heart of the democratic process (Bächtiger et al. 2018).

Deliberative democracy is conceptually in contrast with aggregative democracy which works by aggregating the views of individual citizens without putting them into interaction. The generic example would be voting which is the main mechanism through which liberal democracy works. However, elements of deliberative democracy can be integrated with aggregative elements in practice. For example, deliberation before elections helps with voting by clarifying the positions, views, and stakes. Also, a forum where deliberation and consensus are the norm, voting can sometimes be used as a last resort to be able to come up with a decision (Bächtiger et al. 2018). This is to emphasize that deliberative democracy is not antithetic to liberal democracy which is the conventional model today. Rather, it can be used to support liberal democratic procedures, to render them more informed, inclusive, and consensual.

As can be seen, Kitcher's ideal of well-ordered science resonates well with deliberative democracy. Citizens' informed discussion, their mutual engagement on the basis of sympathetic understanding is best translated into political theory though the framework of deliberative democracy which endorses reasoned and respectful deliberation.

4.1.3 Global Democracy

Another strand of democratic theory which is closely related to Kitcher's ideal is global democracy. It is often claimed that international politics is suffering from a *democratic deficit*. The processes of globalization have generated a complex system of governance at the global level. This system which regulates global affairs is made up of many formal and informal mechanisms and diverse actors other than the nation-state, such as international organizations, NGOs, and firms (Scholte 2014).

These actors are not politically accountable to citizens, and nation-states are only remotely accountable for the decisions taken at the global level since they usually have so little control on their own over these decisions. Therefore, what we see is a global governance system which is becoming more and more powerful, and less and less accountable (Macdonald 2008). It gets more powerful because in contemporary world, many of the most salient issues now unfold at the global level, and decisions on these issues greatly affect many people around the world. The system gets less accountable since it becomes increasingly complex, and nation-states find themselves in an increasingly irrelevant position within it.

Some of the most salient issues at the global level are environmental issues, including climate change. Many scholars argue that we are now entering a new geological era called the Anthropocene, an era which is characterized by large-scale disruptions of the Earth systems due to human activities (Crutzen and Stoermer 2000). Human species has arrived at a point where it had made devastating impacts on the nature and had done so at a global scale. Preventing further disruptions and restoring the damage that has already been done will also require global decisions and actions. John Dryzek makes an important point: it is the human institutions, practices, and modes of thinking from the Holocene, the previous epoch, which have put us down the path to Anthropocene in the first place. To make it through the Anthropocene, we need new global institutions which have "ecological reflexivity"- i.e., the capacity to transform itself based on the feedback coming from both social and ecological systems. Dryzek argues that establishing deliberative democracy at the global level is one way to foster ecological reflexivity (Dryzek and Pickering 2019).

Kitcher's well-ordered science aligns also with the theories of global democracy. Kitcher's ideal involves a globally representative deliberation because he puts forth the all-affected principle: all the people who will be affected by a decision should have a say in that decision. Global democracy's critique of the democratic deficit stems from the same principle. Given its global implications, decision-making on SAI activities is likely to be transported to the global level in the future. Extant governance mechanisms at the global level will fail to generate democratic policies on SAI, just as they failed to do so on climate change for several decades. Instituting a global deliberative forum which is representative of all the humans may help remediate the democratic deficit. It may also lead to more informed and adaptive policies, as Dryzek argues.

4.1.4 Discussion

Based on the theoretical inquiry above, five criteria can be identified as necessary for meaningful democratic input into decision-making on SAI.

First, public participation in SAI should be *informed.* As Kitcher argues, ignorance may lead to decisions which can do great harm to the people who actually endorse these decisions. Uninformed decisions which are taken through formally democratic procedures such as referendum are only superficially democratic. Genuine democracy requires that people have an adequate view of what will promote their interests, and what will hurt them. In the case of science and technology policies, this will involve learning about the current state of scientific knowledge, possible trajectories of research and their estimable consequences, scientific methods, procedures, and standards for certification, and possible applications of scientific knowledge, possibly in the form of new technologies. It is only after going through this learning process that citizens will be able to assess whether any one stage of the scientific activity promotes social and moral values. Moreover, uninformed democratic input would threaten the integrity of science. Illegitimate value influences would undermine the reliability of science. Unreliable science, in turn, could cause harm to many people through unintended consequences, given its privileged position in the system of public knowledge.

Second, public participation in SAI should be *deliberative.* Besides learning about science, citizens should also learn about the perspectives, interests, and needs of their fellow citizens to be able to come up with a well-thought vision of the collective good. This is possible through mutual engagement in deliberation and a willingness to find common ground.

Third, public participation in SAI should be *globally representative.* According to the all-affected principle, all individuals who will be affected by a decision should be able to meaningfully influence that decision. Kitcher's argument for a panhuman participation in science is based on the centrality of science within the (global) system of public knowledge. The actual and potential consequences of scientific findings from one country does not stay confined within that country. Scientific knowledge has the power to bring great misery or great relief to many people around the world. This is all the more valid for SAI: If deployed, it will literally have direct physical impacts on everyone who inhabit the Earth through atmospheric manipulation at a global scale and do so for several generations. To ensure that all viewpoints are included within SAI decision-making, public participation should involve representatives from all geographic and demographic groups in the world. Another requisite of inclusiveness is that all the individuals should have a chance to be part of the participation process. As for the viewpoints of future generations, they will be explored through deliberation.

Fourth, public participation in SAI should be *comprehensive* in the sense that is comprises all stages of scientific activity. Kitcher's extension of well-ordered science to all stages of science corroborates the arguments presented in chapter 1 in favor of a comprehensive public input into scientific activities. People's approval should not be sought solely at the "tips" or the external phases of the scientific process as Douglas puts it - i.e., allocation of funding and authorization for implementing the findings in specific ways. Efforts should be made to engage the public in the internal phases of the scientific process, namely those decisions about research design and hypothesis testing. For this kind of public input into science, providing adequate tutoring and limiting the public input to an indirect role (Douglas 2009) will be crucial. The latter can be done by framing the goal of participation as one of formulating general principles. Scientists can then make a pledge to harmonize their methodological guidelines with these principles, especially for those moments of research that are ridden with epistemic risk. In this way, research practices will be tuned to minimize the errors that are deemed worst by the public.

Fifth, public participation in SAI should be considered *legitimate* by the global society as a whole. While the criteria of being deliberative already encompasses the notion of a fair procedure, this should be made explicit to participants and to the broader public for legitimation. If the public does not perceive the participation mechanism as fair, it will not generate effective democratic input into science and will possibly erode public trust in science further. Kitcher argues that science should not only be well-ordered but should also be recognized as well-ordered. Same goes for the process which is intended to approximate science to the well-ordered ideal: Public participation in SAI should not only be fair, but it should also be recognized as fair. One serious worry about public participation exercises is that they only serve to provide a "seal of approval" from groups of citizens to implement policy decisions that have already been taken (Callon, Lascoumes, and Barthe 2009). Transparency and independence from undue influences are key elements to address such concerns. While public authorities and science organizations may support and contribute to the process, the design of public participation should be such that its outcomes are not pre-determined, and they are perceived as not pre-determined.

How do these five criteria connect to the three arguments in favor of public participation in science that were presented in chapter 1? The *democracy* argument reads as follows: democratic principles require that the public has adequate influence on value-laden decisions in science and technology. The five criteria elaborate on this argument by explicating what adequate influence means in the context of science and technology. They also support the two auxiliary arguments. According to the *sound science* argument, public participation in science can enhance the reliability of scientific knowledge by scrutinizing illegitimate value influences and contributing to science with lay knowledge. A participation process which will engage diverse voices from all around the world in informed and comprehensive deliberation is highly likely to elicit precious insights which can be used to improve scientific practices. As for the *public trust* argument, it is strengthened by all the five criteria. While the first four criteria establishes that the process is well-ordered, the fifth criteria regarding legitimacy ensures that the public acknowledges it as so.

In the next two sections, I turn to extant mechanisms for public engagement in science and technology to assess how they fare in terms of the five criteria I have posited, namely *information, deliberation, global representation, comprehensiveness, legitimacy*. Second section reviews engagement mechanisms other than the deliberative mini-publics and conclude that none of these fulfill all of the five criteria. The third section focuses on deliberative mini-publics which are more promising in terms of realizing the criteria.

4.2 Extant Mechanisms for Public Participation in Science

Public engagement in science can be defined as "the diversified set of situations and activities, more or less spontaneous, organized and structured, whereby nonexperts become involved, and provide their own input to, agenda setting, decision-making, policy forming, and knowledge production processes regarding science (Bucchi and Neresini 2008)." This definition hints at the multitude of ways in which the public can influence science and technology including lobbying, protesting, referenda, surveys, focus groups, citizen panels, community-based research, and so on. Which of these mechanisms that have been put to use until today can meet the five criteria established in the previous section?

4.2.1 Public Communication

Public communication involves one-way information flow from scientists to the public (Rowe and Frewer 2005). It basically intends to increase scientific literacy and interest among the public. Educational mechanisms such as science museums, popular science publications, science journalism, and public hearing are all concerned with communicating complex and possibly controversial scientific issues to the lay people in an effective way. The main goal is to make the public more knowledgeable of scientific developments. This is also assumed to increase public trust in science.

The assumption that an increase in scientific literacy will also increase public trust in science is based on the *deficit model* of the public understanding of science (Wynne 1991) which was the predominant model until the 1990s. The deficit model envisages a unidirectional and pedagogical relationship between the science and the public, and it parallels the value-free ideal of science. Scientific knowledge is the closest we can get to the truth and is definitely superior to lay knowledge. Ordinary people cannot possibly make any meaningful contribution to science because its methods and procedures are simply too complicated for them. They can only offer uninformed opinions and value-based judgments which will deteriorate, not improve scientific activity. The reasonable way to engage public with science is therefore to educate them as much as possible. This way, even though the people do not understand the intricacies of scientific procedures, they will have a good general understanding of science. This will make them support and respect scientists and their work. If the people are currently suspicious towards certain fields of science, it is only because they do not know enough about them. Once they are sufficiently informed, acceptance and trust will come about automatically (Bucchi and Neresini 2008). Consequently, public communication as education was the main mechanism for public engagement in science until the deficit model came under criticism in the 1990s.

Public communication is obviously not an adequate method by itself for public participation in SAI. Basically, it is not a deliberative process since it merely involves one-way information transfer. Still, in can be used to support deliberative mechanisms by enhancing the *information* criteria.

4.2.2 Public Consultation

Public consultation methods also involve one-way information flow, but this time from the public to the public authorities and scientists in the form of opinions (Rowe and Frewer 2005). Generic methods of public consultation include referenda, surveys, opinion polls, focus groups, and submissions in the form of letters or emails.

Public consultation methods have two drawbacks; they are not informed or deliberative. They are not informed because there is no information transfer from the scientists and other experts. People's raw opinions about public affairs are usually uninformed and not well-thought. People usually lack the time and motivation to pay close attention to complex societal issues. They are *rationally ignorant* (Downs 1957). Why bother informing oneself about a ballot issue, for example, if one has only one vote in millions? Since one vote by itself would not make much of a difference, people think it is not worth the pain to inform themselves about policy issues. This is all the more valid for science and technology issues given their complexity. On top of it, public opinion is subject to constant threats of falsehoods and manipulation. Under the circumstances, opinion polls usually capture the surface opinions of the people, their "impression of sound bites and headlines." Sometimes, these may even be "phantom opinions": Some people answer survey questions even though they do not know anything about the issue at hand because they do not want to admit to not knowing (Fishkin 2009).

As for the people who actually pay attention to public issues, they are usually exposed to a narrow range of perspectives. They discuss with like-minded people, they watch the television channels which align with their views, follow social media accounts which confirm their opinions, and so on. People become more and more convinced that they hold the right views, and completely miss the other side of the story (Fishkin 2009). Therefore, the deliberative quality of the broader public sphere is quite low under ordinary circumstances. As conventional surveys do not involve a distinct deliberative mechanism before collecting the opinions, they have to rely on this low deliberative quality.

4.2.3 Social Movements

Since the 1990s, there has been a rise in social movements and public mobilization on science issues. These movements usually engage with science in an adversarial manner. They criticize scientific institutions as an instrument within the broader domination system, serving the economic interests of a minority (Bucchi and Neresini 2008). The paradigmatic case is the protest movement on biotechnologies. They perceive genetically modified organisms as serving only the interests of big agricultural companies. These crops destroy biodiversity and increase the dependency of the global south to the global north by dismantling traditional farming communities (Shiva 1993).

Social movements have become an indispensable part of contemporary politics, not only in developed liberal democracies but in all parts of the world. Protest political participation has expanded in recent decades to encompass an ever-increasing range of subjects, geographies, and populations. Given their prominence and frequency, some scholars even proposed to categorize protests organized by social movements as "normal" political actions, together with conventional ways of political participation such as voting and petitioning (Dalton 2008; Norris 2002).

Some movements have even scaled up to a global level, in the form of coalitions among national and local groups. One prominent example is the global climate justice movement which has successfully linked marginalized groups around the globe, whether they be the urban poor, the small peasants, or the indigenous nations. By drawing attention to the disproportionate harms from climate change inflicted upon vulnerable groups, this movement has contributed greatly to bringing the issue of climate change to the forefront, with a sense of urgency (Tokar 2018). This movement will expectedly have an essential role in public engagement in SAI as well. Many of the risks associated with SAI, namely uneven distribution of regional climatic effects, moral hazard due to vested economic interests, moral corruption as a continuation of historical climate injustice, and ecological injustice, resonate well with the concerns of the climate justice movement. It is likely that in the future, this movement will take on the important task to create public awareness on SAI and to place it on the political agenda.

How do social movements fare in public participation in science, based on the five criteria designated above? Social movements can be strikingly well-informed about the scientific issue at hand, and foster deliberation both within their organizations and the wider public. They may also muster significant support among the society and be recognized as legitimate. There is, however, one shortcoming of social movements: they are not globally representative. There are two reasons for this lack of representativeness. First, even though social movements can be global, joining or even keeping up with the activities of a global social movement would be too demanding for many people around the world. Resources such as time, energy, education, and communication technologies are unevenly distributed around the globe. As a result, the least advantaged demographic groups may be underrepresented in global social movements. In fact, this problem of underrepresentation may be compensated for through deliberate efforts to engage diverse populations in the movement. However, the second reason why social movements are not fully representative cannot be compensated for – i.e., their adversarial nature. Social movements take a position on a societal issue and advocate that position by definition. This necessarily excludes people who do not feel as strongly about that issue, or those who adopt different views. Well-ordered science requires that all attitudes and viewpoints find representation in the ideal deliberation, to the extent that all the people will be affected by SAI.

4.2.4 Community-Based Participatory Research

Community-based participatory research (CBPR) is a bottom-up approach to public engagement in science which has gained prominence in recent decades. CBPR brings scientists and lay people together around a research project which is of high importance to the people who are getting engaged. These are usually patient groups, or local communities who are concerned with environmental and public health issues. One prominent example is the AIDS activist groups in the late 1980s and 1990s. These groups conducted their own community-based trials when scientists refused to do so, and pressurized government agencies to design their drug trials by prioritizing the well-being of AIDS patients. As a result of their efforts, there were radical transformations in biomedical research. Trials without placebo gained recognition and trial groups became more inclusive. Criteria for approving new drugs were loosened. Activists started serving on committees which were responsible for identifying research and treatment options (Epstein 1996).

Another important example of CBPR is the mutual engagement of residents of Woburn in Massachusetts and public health scientists from the Harvard University in 1980s. Concerned with the high number of childhood leukemia cases in their neighborhood, Woburn residents convinced Harvard scientists to help them conduct an epidemiological study. Community volunteers undertook the task of data collection on the location of leukemia occurrences. The analysis of scientists showed that the high number of cases were related to contamination of drinking water by chemicals released from nearby industrial facilities (Brown and Mikkelsen 1990).

CBPR practices are instances of co-production of knowledge where local knowledge becomes an essential part of the scientific knowledge (Callon, Lascoumes, and Barthe 2009). Promoting intense interaction between scientists and lay people, CBPR enhances people's scientific understanding and allows for informed discussion. Moreover, it encourages constant reflection on the choices made during the scientific process and the value influences behind these choices. This way, CBPR can be highly informed and deliberative, and is particularly susceptible for comprehensive participation. Like social movements, however, CBPR fails the criteria of global representativeness. CBPR is a bottom-up engagement model which works best when there is a clear stakeholder group who is distinguishable from the broader public. People who have high stakes in an issue will be motivated to engage and can rightfully claim a privileged place “in the lab”.

By contrast, if SAI will ever be deployed, its effects will be diffuse around the globe. It will be very difficult to identify a small, localized group of people who will be more immediately affected, and who can demand to be directly involved in SAI research procedures. One exception may be those local populations who inhabit an area which is very close to the site of an eventual outdoor experiment or deployment. Nevertheless, their direct participation, if occurs, is likely to be limited solely to the immediate effects of these activities. CBPR approach cannot accommodate a comprehensive participation in SAI research.

4.2.5 Discussion

As presented throughout this section, the diverse public engagement mechanisms other than deliberative mini-publics fall short of fulfilling the five criteria by themselves. Public communication and consultation methods lack deliberative quality. Results from public consultation methods are notoriously uninformed. Social movements and CBPR methods may foster deliberation but usually in a limited sense which does not meet the global representation criteria. CBPR methods involve intense interaction between the scientists and members of the public but do so in an isolated bubble unless further efforts are made to engage the broader public. This was the case, for example, with AIDS activists who pursued a protest movement alongside with their CBPR practices. In fact, it was their activism which provided them a forceful status in the research process.

Social movements will be essential for public engagement in SAI by creating public awareness and placing the issue on the political agenda, possibly at a global level. Nevertheless, they should not be the sole participation mechanism since they fall short of fulfilling the criterion of global representativeness, as discussed in 4.2.3. This lack of representativeness also decreases the deliberative quality within social movements. Surely, systemic approach to deliberative democracy can accommodate adversarial relationships at certain points within the deliberative system. In fact, limited deliberation at one place can enhance deliberation at another place, increasing the overall deliberative quality of the system (Mansbridge et al. 2012). This is evident in social movements’ capacity to bring an issue to the deliberative agenda. Still, for a distinctively global issue such as SAI, the central participation mechanism should be one that can meet the criterion of representativeness along with the four other criteria. By central participation mechanism, I mean the mechanism through which those policy recommendations that will be directly addressed by decision-makers will be formulated. If this mechanism were to be a social movement, then public participation in SAI would probably take the form of a tri-partite negotiation between the movement, politicians, and experts. Such a process would exclude the viewpoints of those people who are not part of the movement due to lack of capacity, lack of interest, or divergence in attitudes. Therefore, the central participation mechanism for SAI should be a global forum where representatives from all around the world and from all demographic and attitudinal groups will come together and deliberate on SAI in a respectful and inclusive environment. Social movements will, on their part, have crucial supportive roles on the way to establishing and maintaining this forum. In the next section, I turn to deliberative mini-publics as a possible model for the global forum on SAI.

4.3 Deliberative Mini-Publics

Deliberative mini-publics are innovative mechanisms for public engagement which have gained popularity in the last three decades. Basically, they are citizen forums where people come together and deliberate on a specific issue of common concern. These are usually policy issues that require complex trade-offs such as infrastructure, urban planning, environment, and health (OECD 2020). While the main deliberation takes place among the citizens, other actors such as experts, scientists, stakeholders, and policy-makers also contribute to the process by providing information and perspectives. The results of this deliberation then provide input to the policy-making process (Setälä and Smith 2018). The goal is to arrive at a considered public judgment rather than immediate public opinion through discussion and reflection (Yankelovich 1991).

Robert Dahl's proposal for a "minipopulus" has been the guiding idea for many experiments with deliberative-mini publics. Dahl envisages a citizen assembly representative of the broader population, consisting of around one thousand people. The minipopulus deliberate on an issue at length, for example over a year, then present their recommendations to the public and the legislature. This way, they complement the legislature process as a consultative body. Their views represent the public judgment under good conditions – i.e., when it can benefit from the best available knowledge to realize its ends (Dahl 1989).

Over the last three decades, various deliberative mechanisms have been designed and implemented around the world with the joint efforts of scholars, civil society organizations, and policy-makers. While they come in many different forms, many of them have certain common features. First, participants are usually selected through stratified sortition to ensure representativeness and inclusivity. Second, participants go through a learning process to ensure informed discussion. Third, the discussion is structured in a way so as to maintain its deliberative quality (Setälä and Smith 2018). Thanks to these specific design elements, deliberative mini-publics can possibly foster informed, deliberative, globally representative, comprehensive, and legitimate public participation in SAI. In fact, deliberative mechanisms have already been implemented numerous times for controversial science and technology issues such as biotechnologies, genome editing, and nanotechnologies.

The next two subsections present a review of different mini-public designs. It is important to note that this is not an exhaustive review. I focus on those mechanisms which have been widely implemented or been used at a multinational scale. I group the mechanisms under two types based on the form of their final outcome. Type 1 deliberations end with a collection of informed opinions or short, bullet-point recommendations. Type 2 deliberations produce a much more detailed document, a final report of policy recommendations. As will be discussed at the end of this section, the main process for public participation in SAI would preferably be of type 2. However, type 1 mechanisms can also be used to feed broader public input into the main process.

4.3.1 Type 1: Informed and Considered Public Opinion

As indicated above, type 1 deliberative mini-publics produce a collection of informed and considered citizen opinions on a public issue. Since the deliberators do not have to compile a report of citizen recommendations on the issue, type 1 mechanisms last shorter than type 2 mechanisms, usually two to three days. Still, type 2 mechanisms have certain design elements which ensure that they are informed and deliberative as opposed to conventional public consultation exercises.

4.3.1.1 Deliberative Polling

Deliberative Polling is an invention of political scientist James Fishkin. It is distinguished from regular public opinion polls by incorporating informed deliberation. Basically, it consists of two opinion polls with group deliberation in between. The process has four stages. In the first stage, a random sample which is representative of the broader public is polled on the issue of interest. Second, members of the sample come together, usually for a weekend, to participate in small group deliberations. The groups are formed with demographic and attitudinal representativeness in mind, with an aim to make sure that a variety of views come into interaction during deliberation. The deliberations are informed by briefing materials which are carefully prepared by an advisory committee to strike a balance between competing views. The deliberations are moderated to ensure that civility is maintained, and all voices in the group have a fair hearing. Third, after the deliberations, the participants join a session with competing experts and politicians where they can ask their questions formulated during deliberation. Parts of the deliberations are broadcasted, and all briefing materials are made publicly available to reach out to the wider public and ensure transparency. Fourth and finally, the event is concluded with post-surveys in which the participant individuals are asked the same questions as those in the initial survey. This way, it becomes possible to measure the change in opinions after informed and considered discussion. In many cases, substantial changes in opinions have been observed (Fishkin 2009).

The aggregate results to the final survey give the counterfactual public opinion which would have been if the public as a whole had the chance to become informed about and involved in key public issues, considering the relevant trade-offs. This, according to Fishkin, is the crystallization of the genuine public will which should be the basis of democratic decisions. Indeed, the end results from deliberative polls usually inform public policy (Fishkin 2009).

So far, the process has been used over 100 times in 29 countries on six continents (Stanford Center for Deliberative Democracy N.d.). Deliberative polling has also been used in a transnational context. EuroPolis was an EU-wide deliberative poll which brought together participants from 27 EU countries in 2009 soon before the European parliament elections. The participants deliberated on their voting preferences, climate change, and immigration. Everybody had a chance to speak in their own native language both in the group discussions and the plenary sessions thanks to simultaneous translation in 21 different languages (Isernia and Fishkin 2014). This successful implementation of a transnational deliberation is promising for the prospects of a global deliberative forum on SAI.

4.3.1.2 Citizens' Dialogue

Citizens' dialogues are used to gather broad opinions, comments, and questions from the citizens, following very brief learning and deliberation processes. They are short events of one to three days, and on topics many citizens are already familiar with. Citizens' dialogues have been widely used at the local and national levels across countries. They can also be used as part of a larger public engagement strategy (OECD 2020).

Particularly interesting are several citizens' dialogues which have been conducted at the multinational level. The European Commission has organized two transnational citizens' dialogues in 2019 and 2020. The first one took place on one single day in The Hague, and brought together 120 citizens from Belgium, France, the Netherlands, Germany, and Ireland. By help of simultaneous interpretation, participants discussed on issues of "social Europe, digital Europe, and global Europe." These discussions culminated in short questions and comments which were communicated in person to a responsible from the European Commission (European Commission 2019). The second one was quite similar to the first one except that it was fully digital, lasted three days, and involved a different set of countries (Denmark, Germany, Ireland, Italy, and Lithuania) (European Commission and Bertelsmann Stiftung 2020).

Besides these transnational dialogues at the European level, there have also been two recurring citizens' dialogues at the international level which involve greater numbers of countries. Contrary to European transnational dialogues, these international dialogues do not bring people from different countries in a single deliberative forum. Instead, they aggregate results from distinct national-level dialogues.

The first international dialogue is *World Wide Views* developed by Danish Board of Technology. So far, the method has been used to inform United Nations Climate and Biodiversity Conferences of the Parties (COPs) on three occasions. In 2009, 4000 citizens from 38 countries deliberated and polled on climate change. In 2012, 3000 citizens from 25 countries did so on biodiversity loss. In 2015, 10.000 citizens from 76 countries discussed and opined on climate and energy on the road to the Paris Agreement on climate change. *World Wide Views* takes one full day and involves simultaneous citizens' dialogues in many countries across the world. All of these dialogues use standardized materials and format. First, citizens are informed through video material. Second, they engage in small-group deliberation in their national citizens' dialogues. Finally, citizen opinions are gathered in the form of individual votes on key aspects of the issue at hand. Individual votes are aggregated at the global level and publicly announced on the internet. The voting results present a fairly well-thought global public opinion on issues of climate change and biodiversity (World Wide Views N.d.).

The second international citizens' dialogue is *We, The Internet* project undertook by Missions Publiques, a Europe-based social entrepreneur group. Its aim is to collect considered citizen opinions on the future of the Internet to inform policy-makers and other relevant actors. In collaboration with national partners, *We, The Internet* organizes one-day deliberation events in separate countries, then compiles citizen opinions from these events in the form of individual and small-group questionnaires. Their latest organization took place in 2020, in more than 70 countries with over 5000 individual participants (We The Internet N.d.).

The citizens' dialogue format, by itself, is not very convenient for public participation in SAI because the information and deliberation phases are too short, and the end results are not detailed enough. Nevertheless, just as with the EuroPolis, the successful implementation of this format at the multinational level is encouraging for conceiving a global forum on SAI. Global citizens' dialogue may also be considered to provide broader public input in a longer, comprehensive participation process occurring in a smaller deliberative mini-public.

4.3.2 Type 2: Collective Citizen Recommendations

Type 1 and 2 mechanisms are similar in many respects: Both types involve stratified random sortition based on demographic and geographic representation. Both types consist of roughly three phases: learning, deliberation, formulation of final outcomes. Both types have been widely used across countries to inform policy decisions. Their main difference is in regards with the format of their final results. As we saw in the previous sub-section, type 1 ends with broad aggregation of individual or small-group opinions. Instead, type 2 produces a collective report of policy recommendations endorsed by a majority (usually a supermajority) of the mini-public. Since this endorsement requires considerable discussion, weighing, and concession among different viewpoints, the deliberative quality of type 2 mechanisms is higher. They come up with a genuinely collective opinion. Moreover, the final report is usually fairly detailed, with explanations and reasons provided for each recommendation. Since formulating such detailed recommendations require thorough learning and deliberation, type 2 usually lasts longer than type 1. Based on its length, the process can be condensed in consecutive days, or spread out over several weekends (OECD 2020).

4.3.2.1 Citizens' Jury

Citizens' Jury was established much earlier than Consensus Conference. It was invented by political scientist Ned Crosby in the US in 1971 (Crosby 1995). It has been adapted to many countries and has been widely used at both the local and the national level to address various policy questions such as infrastructure, urban planning, health, and environment. It usually involves 12-26 randomly selected citizens and takes place on 2-5 consecutive days. The versions of Citizens' Jury developed in Australia and Canada involve a higher number of participants (36 to 45) and are spread over several weekends (Escobar and Elstub 2017; OECD 2020).

As explained above, the process consists of three phases: learning, deliberation, and formulation of final recommendations. Learning phase involves briefing material in various formats such as booklets and videos. A diverse range of experts are invited over to make presentations and hold Q&A sessions. Moreover, public hearings and stakeholder consultations may be organized to learn the issue from diverse viewpoints. Citizens' Juries can also be combined with other public engagement mechanisms such as community meetings, online submissions, and surveys. Deliberation phase builds upon the learning phase in that it involves informed, evidence-based, and reasoned discussion through which diverse policy options are evaluated. The discussion is facilitated to preserve respect among the participants, and to ensure that all of them have their fair share of time and attention to express their views. In the final phase, citizens come up with collective recommendations under the name of a "verdict" which is then presented to the relevant public institution to guide policy-making on the issue at hand (Crosby 1995; OECD 2020).

4.3.2.2 Consensus Conference

Consensus Conference was developed by Danish Board of Technology in 1987 with an aim to guide science and technology policies (Joss and Durant 1995). Consensus Conference involves 10-25 citizens and takes place on 7-8 days (Escobar and Elstub 2017).

The learning phase takes place on a preparatory weekend. During this phase, participants of the conference, called the citizen panel, come together and study a given science and technology issue in depth. They also learn about the process and get to know each other. In the end, they come with a number of questions that they will direct to the expert panel – i.e., a group of experts consisting of scientists, professionals, and policy-makers (OECD 2020).

The second phase comprises the expert panel and deliberation. Expert panel takes place first, with experts making presentations on their perspectives and the citizen panel asking their questions prepared earlier on. This serves as an occasion for the citizens to clarify their minds on the issue before delving into deliberation. Citizen panel also have a chance to choose the experts who will make presentations beforehand (OECD 2020).

The deliberation phase is similar to the one in citizens' juries. However, the final phase of formulating and presenting recommendations has some distinctive properties. First, citizens are required to reach a consensus on their collective recommendations. Second, citizens present their final report to the experts in person and get an immediate reaction from them. Politicians are also present, and they debate on the recommendations. Third, this stage is open to the wider society and the press. This way, citizen recommendations become publicized (OECD 2020).

4.3.2.3 Citizens' Assembly

Citizens' Assembly first originated in Canada in the early 2000s. Citizens' Assembly can be thought of as a scaled-up version of Citizens' Jury. Like Citizens' Jury, Citizens' Assembly consists of three phrases: Learning, deliberation, and deciding on final recommendations. However, each of these processes are much deeper and considerably longer in Citizens' Assembly, ranging between 20-30 days in total and spread over several weekends. They also involve a much higher number of participants, around 100-160 people (Escobar and Elstub 2017). Given their high number, participants spend most of the deliberation process in smaller groups. This way, they have a chance to effectively deliberate as well as to get to know each other. Later, they vote for the recommendations formulated in the group deliberations during plenary sessions (Warren and Pearse 2008). Recommendations are accepted with a majority vote, and there may be a minority report recognizing the viewpoints which could not obtain a majority (OECD 2020).

The reason why Citizens' Assemblies are much larger and lengthy is that they typically tackle more complex issues with wide-ranging consequences at the national and/or global level. For instance, the first two Citizens' Assemblies convened in two provinces of Canada (British Columbia in 2004 and Ontario in 2006) to come up with a proposal for a new provincial electoral system. Around 100 randomly selected citizens worked over numerous weekends over months to learn about the complexities of electoral systems and came up with detailed recommendations which were then put to referenda in the provinces (Warren and Pearse 2008).

Another important feature of Citizens' Assemblies is extensive publicization. Since the agenda of Citizens' Assemblies are matters of common concern for all citizens, efforts are made for effective public communication to engage the broader society in the process as well as to ensure social legitimacy. In this regard, Citizens' Assemblies put up their own websites where all the relevant information regarding the process is made public. Specifically, explanation of the procedures for participant selection and for all the subsequent phases, materials used in the learning phase, stakeholder presentations, videos of parts of deliberations are made available online. At the end of the process, recommendations are announced in a press conference and presented to the public authority who commissioned the assembly. This authority is expected to respond to the recommendations in due time. At the very end, full report, summary reports, and the government response are all made available online (OECD 2020).

Due to their demanding structure, Citizens' Assemblies have not been very frequently employed. Besides Canada, Citizen Assemblies have so far been implemented in Ireland, France, and UK. The 2016-2018 Irish Citizens' Assembly addressed long-standing and difficult issues of same-sex marriage, abortion, and climate change. Based on the final recommendations of the Citizens' Assembly, the Irish parliament called for a referendum on amending the constitution article on abortion and declared a climate emergency (The Citizens' Assembly N.d.). Other notable examples at the national scale are the French and British Citizens' Assemblies on climate change held on 2019-2020 and on 2020 respectively (Climate Assembly UK N.d.; The Citizens' Convention on Climate N.d.).

Recently, there have been efforts to transpose the Citizens' Assembly format to the global level (Abati and Lee 2020). To my knowledge, there are three such ongoing projects: The Global Assembly on climate change (Global Assembly N.d.), the Global Assembly on Genome Editing (Global Citizens' Assembly on Genome Editing N.d.), and the World Citizens' Assembly for global agenda-setting within a system of single-topic Global Citizens' Assemblies (World Citizens' Assembly N.d.). All the three global Citizens' Assemblies are currently under preparation; therefore, they have not convened yet. If they succeed, they will mark the birth of a public participation design which is both deliberative and globally representative. These projects are in line with Dryzek and his colleagues' proposal of a system of deliberative global citizens' assemblies to remediate the democratic deficit in global governance (Dryzek, Bächtiger, and Milewicz 2011).

To illustrate how a Global Citizens' Assembly could work, here I sketch the process envisaged by the organizers of the Global Assembly on climate change.

The long-term goal of the project is to establish a permanent Global Assembly as an integral part of the global climate governance by 2030. As for the short-term goal, it is to present recommendations that will be formulated in the Global Assembly to the upcoming COP26 meeting in November 2021, and to receive an official response. This year, a pilot assembly will bring together 100 people from all around the world selected through stratified sortition[2] on a digital platform where they will engage in informed multilingual deliberation by help of simultaneous interpretation. The organizing team is planning to scale up to 1000 citizens in 2022. To broaden participation, local partner organizations will be allowed to run distributed events using the same materials and processes as in the core assembly. Furthermore, various mechanisms are envisaged to engage governments, businesses, civil society, cultural actors, and the media (Global Assembly N.d.).

4.3.3 Discussion: Proposal for a Global Citizens' Assembly on SAI

The public engagement mechanisms reviewed in section 2 fell short of fulfilling at least one of the five criteria for meaningful public influence on SAI: *information, deliberation, global representation, comprehensiveness, legitimacy.* The criterion for global representation was conspicuously absent in all of the mechanisms. Public communication mechanisms involved no representation at all, they were just unidirectional information transfer from the scientists to the society. Even though one can conceive a public consultation exercise scaled-up to the global level, without information and deliberation those opinions cannot adequately guide the trajectory of science and technology. Community-based participatory research engaged scientists closely with a localized community of lay people and was not susceptible to be transported to the global level. While social movements fared the best in terms of global representation, they still did not satisfy the criteria sufficiently. They necessarily excluded certain groups of people because they are adversarial and require resources that many people around the world are still in dearth of. I concluded the discussion at the end of section 2 by suggesting that deliberative mini-publics may fare better than other types of public engagement methods to realize the five criteria, especially regarding global representation. Based on the review presented in this section, what comments can be made on this suggestion? Should mini-publics really be the main participation mechanism for SAI? Which mini-public format seems preferable to others? It will attempt to answer these two questions simultaneously.

[2]Stratification is based on key demographic indices, countries, and regions. An online sortition event has recently happened on June 24th, 2021, to designate the locations from which the 100 participants of the 2021 assembly will be selected. Video recording of the event is available on livesortition.globalassembly.org (accessed 30.06.2021).

First, due to their special design elements which incorporate learning and deliberation, mini-publics readily meet the criteria of *information* and *deliberation*. A distinct learning phase beforehand ensures that the discussion is informed, evidence-based, and reasoned. Facilitated deliberation maintains mutual respect among the participants. It also ensures that all perspectives find due expression and are weighed based on their merit. However, throughout the section, I have argued that type 2 mechanisms fare better than type 1 mechanisms in terms of *information* and *deliberation*. Even though type 1 exercises have a learning phase, this is usually much shorter compared to those in type 2. This surely affects the depth and range of the ensuing discussion. Moreover, participants of a type 2 have to come up with a collective recommendation endorsed by a majority. Therefore, the discussions in type 2 involve listening diverse viewpoints and arguments, weighing possible trade-offs, and coming to a considered collective judgment through concession and compromise. These are all essential elements for high quality deliberation. By contrast, type 1 mechanisms do not produce genuine collective recommendations. They finish with the aggregation of individual or small-group opinions, without attempting to reconciliate and synthesize the disparate viewpoints. Therefore, discussions in type 1 can afford to be much more casual and less deliberative since the individuals do not have to arrive at a collective agreement. In short, while all mini-publics have informed and deliberative qualities, these are expected to be much higher in type 2 mini-publics. Finally, type 2 mechanisms are preferable to type 1 in terms of the *information* criteria also at the systemic level. Since the final report is a fairly detailed document, it can be used to inform other deliberations that occur at various locations within the deliberative system: governments, universities, civil society organizations, other mini-publics, the broader public sphere, and so on. If the mini-public is iterated, reports from earlier iterations can serve as a basis for deliberation in later ones. By contrast, the end results of type 1 exercises are survey results or bullet-point comments and recommendations, without any detailed explanations and supportive arguments formulated by the public themselves. Therefore, they can barely give a sketch of the counterfactual public opinion if people were fairly better informed than they currently are. Maybe, it is even better to think of them as enhanced public consultation exercises rather than genuinely deliberative forums.

Mini-publics can also meet the *global representation* criterion thanks to the method that they use to select participants – i.e., stratified sortition. This method randomly selects people from the target population with quotas and limits for the main demographic (age, gender, income) and geographic groups. If applied at the global level, this method could generate a snapshot of the whole world population, a "mini-world" with people from the four corners of the earth and from all walks of life. However, to be able to encompass the enormous diversity of the global population, the mini-public should be as large as feasibly possible. This requirement readily rules out smaller mini-public formats such as Citizens' Jury and Consensus Conference. The largest mechanisms that have so far been employed are the global Citizens' Dialogues, namely *World Wide Views* and *We, The Internet.* Even though they may at first seem as the most representative mechanisms due to their sheer size, a closer look at their recruitment processes casts doubts on this impression. Both projects admit that there is considerable self-selection going on at their localized Citizens' Dialogues which is prone to skew the participant profile in favor of certain demographics. When working with thousands of people from dozens of countries, it is very difficult to monitor recruitment process so as to make it as representative as possible of the actual population. Regarding *global representation*, the optimal mini-public would be just large enough so that it could simultaneously accommodate global diversity and be manageable in terms of proper random sortition, with possibly a few hundreds of people. Citizens' Assemblies and Deliberative Polls can both meet this requirement. Since the latter is a type 1 mechanism, however, I rule it out due to its shortcomings in terms of *information* and *deliberation* that have been discussed above. Therefore, based on the discussion so far, Citizens' Assembly seems to be the only extant mini-public design which can be *informed*, *deliberative*, and *globally representative*, all at the same time.

How do different mini-public designs fare in terms of *comprehensiveness*? Which designs are more likely to allow for public input concerning all stages of science? Obviously, type 1 exercises are simply too short and too superficial for this purpose. Citizens' Assembly seems to be the best design at hand also for comprehensive participation. The Citizens' Assembly format includes a thorough learning phase, with expert presentations and QA sessions over numerous weekends and with rich reading materials in between. This way, the participants will be able to grasp the intricacies of scientific processes and to formulate informed recommendations for all stages of science.

Finally, I argue that Citizens' Assembly fares best in terms of *legitimacy.* Legitimacy requires that the process be fair and be recognized as fair by the broader public. If done properly, global sortition will ensure that everyone on the Earth will have a chance to be selected to the assembly, and stratification will safeguard proportional representation of relevant populations. Thanks to the balanced design of the learning process, participants will learn about different views on SAI. This way, the deliberations will not be biased in favor of certain perspectives. Facilitated deliberation provides that all the voices are being heard and considered, in an environment of equality and respect. Endorsing of the final report through majority vote and inclusion of minority views in a side report will ensure democratic decision-making, all the while acknowledging diversity of interests. Finally, public efforts for public communication and broader public engagement, and transparency will help achieve legitimacy of the process in the eyes of the broader public.

To conclude, I argue that Citizens' Assembly is the most suitable mechanism of public participation in SAI. It can possibly meet all the five criteria for meaning democratic input, *information, deliberation, global representation, comprehensiveness, legitimacy*. However, other approaches such as public communication, social movements, and global Citizens' Dialogues can also be used to support the activities of the Citizens' Assembly. In fact, I would expect such an assembly to be established thanks to the efforts of a social movement against SAI. Currently, the global environmental movement Extinction Rebellion is urging for the establishment of national Citizens' Assemblies to guide governments on climate and environmental policies (Extinction Rebellion UK N.d.). Moreover, the French Citizens' Assembly on climate change was a direct result of the Yellow Vest movement (OECD 2020). Therefore, I close this discussion by emphasizing that deliberative mini-publics and other mechanisms of public engagement are not mutually exclusive. On the contrary, they are often mutually supportive. Then, the real question is: Which public participation mechanism should be the central mechanism, given our aim of democratization of SAI? Based on the discussion above, I conclude that a Global Citizens' Assembly should be established for public participation in SAI.

4.4 Limitations

In this final section, I attempt to address some of the limitations of my proposal for a Global Citizens' Assembly on SAI. Specifically, I discuss worries about public incompetence, infeasibility and public apathy, and lack of impact.

4.4.1 Public Incompetence

One general worry about deliberative mini-publics is that the public does not have the resources or capacities to engage in such a penetrating participation process in decision-making. According to this view, ordinary people simply do not have the educational background or life experiences to come up with informed and reasonable recommendations that can validly guide policy-makers. This is all the more conspicuous concerning science and technology issues which involve highly specialized knowledge. Placing trust in the lay people to formulate any useful recommendation to guide scientists would be daydreaming, let alone a comprehensive participation process encompassing all stages of science. Besides being a futile effort, this latter would also pose serious risks to the integrity and reliability of the scientific process.

Admittedly, the state of scientific literacy within the broader public is not very bright. Particularly, there are still many regions of the world which have very low access to education, such as sub-Saharan Africa (Cago 2017). This is all the more concerning for public participation in SAI, since sub-Saharan Africa is one of the regions that are most vulnerable to climate impacts. Populations inhabiting these vulnerable regions have the most stakes in decisions about SAI: Ultimate decisions about whether to deploy or not, and all the previous decisions taken during the scientific process that culminated in those ultimate decisions. According to the proportionality principle of democracy, those people who have higher stakes in a decision should have privileged influence over that decision (Brighouse and Fleurbaey 2010). Unfortunately, we are in a situation in which those people whose participation is most crucial have the least means of doing so.

Shortcomings regarding the public incompetence and the inequitable distribution of competence across the globe should intensify efforts for public participation instead of discouraging them. It is important to remember that deliberative mini-publics are also learning processes. Their participants have the chance to learn about not only complex societal issues, but also civic engagement and democratic practice. Moreover, the global Citizens' Assembly on SAI is conceived not as an isolated, one-time endeavor. Instead, it is designed to be an iterative one with deep connections to the broader society. As time passes, more and more people will have a chance to engage in the process, enhance their knowledge, and share this knowledge in their own communities as trusted information proxies (MacKenzie and Warren 2012). In the long run, this will enhance both scientific literacy and deliberative quality within the whole deliberative system. Concerns about comprehensive participation undermining scientific integrity can also be addressed within this iterative framework. The range and depth of public participation in the scientific processes can be progressively increased as people's understanding of science increases. In short, incompetency is a serious difficulty in establishing a global Citizens' Assembly on SAI, but also -and more importantly- a pressing reason to do so. In addition, worries about public incompetency are probably overrated. Empirical studies show that when given enough resources, citizens can come up with high-quality, insightful recommendations even on complex or controversial issues (Escobar and Elstub 2017). One reason may be that groups composed of diverse individuals are better in problem-solving than homogenous groups of experts (Hong and Page 2004). Deliberative mini-publics will produce thoughtful recommendations when they are composed of people from diverse backgrounds (Landemore 2013). Therefore, the image of an incompetent public may after all be a residue of the deficit model of public understanding of science.

4.4.2 Infeasibility, Public Apathy

There will also be concerns about the feasibility of a global Citizens' Assembly on SAI. First, Citizens' Assemblies are very costly and demanding exercises even at the national level. Scaling them up to a global scale will require huge amounts of resources and commitment. Authorities will probably refrain from investing in such an expensive endeavor; many people will not have the time and resources to partake in such a time-consuming project. In fact, people are usually apathetic about societal issues; they simply do not want to engage in deliberation unless it is really necessary (Hibbing and Theiss-Morse 2002). Moreover, it will be very difficult to sustain coordination among a myriad of local, national, and global organizations who will be involved in the process. Preparation and implementation of a global Citizens' Assembly will simply be too complicated and unwieldy.

Establishing the global Citizens' Assembly on SAI will admittedly be costly in an absolute sense. However, costs should be relativized according to the context. That is, the costs of organizing a global Citizens' Assembly on SAI should be weighed against the costs of not doing so. Without adequate public scrutiny of SAI, there is the risk that this technology is developed with little or no regard to the common interests of the global population. As discussed at length in the first two chapters, this would be an intolerable breach of democratic principles. Therefore, one should carefully weigh the costs and benefits of building to a global Citizens' Assembly. In doing so, one should also consider its broader benefits in terms of enhancing public understanding of science, deliberation, and civic culture at the systemic level. As for the reluctance of citizens in joining such assemblies, there is empirical evidence that people may be much more willing to participate in deliberative processes than what is commonly thought (Neblo et al. 2010). Also, people who join deliberative mini-publics usually express great satisfaction with the process and become strong supporters afterwards (Curato and Niemeyer 2013). Thus, we can expect that as usage of deliberative mini-publics become more widespread at all levels, people will be more willing to participate in such projects. Finally, digital tools can help in various ways to make the global Citizens' Assembly on SAI more feasible. First, digital communication platforms allow for conducting possibly the whole process online. Indeed, this is the strategy adopted by the Global Assembly on climate change for their pilot assembly this year (Global Assembly N.d.). Second, digital tools will also streamline the organization process and coordination among actors all across the globe. Finally, these will considerably decrease logistics costs.

4.4.3 Lack of Impact

Finally, it may seem doubtful whether the global Citizens' Assembly on SAI will have any substantive impact on SAI research and governance and the public opinion. Recommendations from deliberative mini-publics are most impactful when the event has been commissioned by a public authority who has pledged to respond these recommendations beforehand (OECD 2020). There are currently no public authorities, national or international, who have assumed the rule of regulating SAI activities. If a global Citizens' Assembly convened under these circumstances, it is not likely that their final report will find an addressee in the political sphere. However, this may change in the future. In 2019, Switzerland submitted a resolution to initiate discussion on geoengineering governance to the 4th session of the UN Environment Assembly. While the resolution was blocked by United States and Saudi Arabia, it attests that climate geoengineering gives concern to at least some states (C2G N.d.; Watts 2019). Future attempts may successfully put governance of climate geoengineering, and specifically of SAI research, onto the international agenda. An expert report on governance of SAI research advises that a global forum for broad stakeholder engagement in SAI, including public participation, should be created by a consultative Commission mandated by the UN General Assembly, like the Brundtland Commission. This is a feasible institutional design, even though it is difficult to foresee whether it will take place any time soon, or ever.

Another possibility for public participation in SAI is that the initiative may come from SAI scientists themselves. Aware of the uncertainties, risks, and public controversies around SAI, the research group at Harvard University has been attentive to establishing a transparent governance scheme through an independent Advisory Committee. As discussed in Chapter 2, this committee has postponed an outdoor experiment in Sweden due to upheaval from local Saami communities inhabiting the area around the experiment site. In their address to the research team, the committee required robust public engagement before proceeding with the experiment. The opposition letter of the Saami Council concludes: "Stratospheric Aerosol Injection research and technology development have implications for the *whole world*, and must not be advanced in the absence of *full, global consensus on its acceptability* (Saami Council 2021, emphasis added)." While it is not likely that a global public engagement mechanism will be put in place from the very beginning, the current deadlock in research may create an opening for engagement which may eventually scale-up to the global level.

5. CONCLUSION

Climate change is advancing at a dangerous pace. Lack of decisive action within the economic and political spheres for tackling climate change has been disheartening. Fearing that the necessary systemic changes for effective abatement might not be arriving any time soon, scientists started research into technological means to help alleviate the worst effects of climate change, known as climate geoengineering.

On the one hand, climate geoengineering technologies may possibly be effective tools in decreasing global temperatures to prevent them from exceeding critical thresholds. On the other hand, they also involve serious costs and risks; tinkering with the atmosphere is no light task. Either way, eventual implementation of these speculative technologies will largely affect many people around the world. Therefore, according to democratic principles, people should be able to meaningfully influence decisions related to these technologies. However, science has traditionally been an autonomous, self-governing domain. Standard view of science invokes isolation of science as an institution from politics and society as a precondition to safeguard its integrity. As such, social values have no role to play in scientific activities and would only undermine the reliability of their outcomes. Drawing on a critical literature in philosophy of science, I challenged the standard view of science and the value-free ideal in chapter 1. Science is never a purely technical, value-free activity. Even decisions related to research design, methodology, and hypothesis testing which come up in the very heart of science cannot be made based solely on logic and evidence. Because evidence is never conclusive, science is inherently uncertain, and ridden with epistemic risks. Coming to conclusions under uncertainty requires an evaluation of the consequences of making an error for each possible conclusion. For instance, concluding whether a climate geoengineering method will be effective and safe based on limited evidence requires answering the question: “Which one is worse? Concluding that it is effective and safe when it is actually not, or concluding that it is not effective and safe when it is in fact so?” Since such questions cannot be resolved by available evidence, value judgments necessarily come into play. This is all the more valid for the science of climate geoengineering, given the complex nature of the climate system. Climate science in general is rife with uncertainties, and conclusions of research depend heavily upon modelling choices made earlier. Public participation is necessary to ensure that value-laden decisions in science pay regard to the collective preferences of society. Subsequent decisions to proceed with the development, experiment, and implementation of a climate geoengineering technology will depend upon the value-laden decisions that were made earlier. Therefore, public participation should start early on, comprising all stages of scientific activity.

In this thesis, I focused on one of the speculative climate geoengineering technologies – Stratospheric Aerosol Injection (SAI). SAI is a proposed method to cool the Earth's surface by spraying sulphates or other aerosols in the stratosphere which will form a reflective sunshade around the Earth. The discussion in chapter 2 illuminates the reasons why we should be specifically concerned with SAI in the context of public participation in science, which can here be summarized in two points. First, SAI is one climate geoengineering scheme which has the potential to be implemented relatively soon. Available research suggests that the effects of SAI will be quick and global, whereas other geoengineering schemes are expected to show their cooling effect either slowly or at a regional scale. Moreover, it is inexpensive and technically feasible, making unilateral deployment by a single state or even by a very wealthy private actor possible. Considering the galloping speed at which climate change is currently advancing, it is not unrealistic that some authorities will make calls for an SAI deployment in a relatively near future, in the context of a "climate emergency". Second, the factors which make SAI a likely candidate for deployment are coupled with serious uncertainties and risks. In addition to the uncertainties of climate models mentioned above, SAI models bear additional uncertainties about the behavior of aerosols in the atmosphere, with a very limited set of data from a handful of volcano eruptions informing modelling decisions about them. Current conclusions about the effectiveness of SAI may indeed be spurious. Even if SAI will effectively cool the Earth, its regional effects on temperatures and precipitation are not known with sufficient accuracy. In other words, SAI may put regions that are the most vulnerable to climate disruptions under even greater stress. To add, probably the greatest physical risk of SAI is the termination shock - an abrupt increase in temperatures in case SAI deployment had to be ceased, which would have even worse effects than runaway climate change. Despite these uncertainties and risks, certain actors with vested interests in economics, politics, and science itself may push for the development and premature deployment of this risky technology. There are serious concerns about a moral hazard which would reduce incentives for abatement, and a slippery slope from research to deployment. As established in chapter 1, decisions in science which will possibly have significant impacts on the public, and which involve great uncertainties, should not be made without due democratic influence. Since SAI involves many such decisions, public participation in SAI is imperative.

In chapter 3, I investigated what due democratic influence means in the context of science and technology based on three theoretical strands: Kitcher's well-ordered science, deliberative democracy, and global democracy. I came up with five principles which should guide public participation in science: *information, deliberation, representativeness, comprehensiveness, legitimacy.* In regard to SAI, the criteria for representativeness necessarily took on a global character. Since the effects of SAI will unfold at a global scale, the relevant public is the "global public". Therefore, a global forum for public participation in SAI should be established. This is a striking conclusion because exercises of public participation in science have so far been realized at the national scale. If established, the Global Citizens' Assembly for SAI which I advocate for will be the first[1] global public participation mechanism in science. Moreover, even though a few global Citizens' Dialogues have been realized on the topics of climate change and the internet, these exercises had low deliberative quality due to their short and rather shallow phases of learning and deliberation. Therefore, the Global Citizens' Assembly on SAI, as it is delineated in chapter 3, is candidate to be the first ever global public participation exercise with genuine deliberative quality. As humanity will advance further into the Anthropocene, environmental problems which require global regulation based on scientific expertise such as climate change will become increasingly challenging. Traditional political institutions have dismally failed in addressing such problems. Building democratic and deliberative structures early on within the global governance system will increase our capacity, as humanity, to face these problems by fostering ecological reflexivity.

In this thesis, I pursued a novel research trajectory at the crossroads of three distinct branches of literatures: Philosophy of Science and Science and Technology Studies, research on SAI from both natural and social sciences, and deliberative democracy. Future theoretical research should ground the Global Citizens' Assembly and similar institutional designs more firmly in both philosophy of science and democratic theory. The implications of using deliberative mini-publics for public participation in science should be explored regarding the scientific practices as well as the prospects of conventional democratic (and non-democratic) political practices. Empirical research should investigate the effects of difference design

[1] Or one of the first, to be precise, if we consider the Global Assembly on Genome Editing which is currently under preparation.

choices regarding recruitment, timing, learning materials and processes, group deliberation, formulation of recommendations, and follow-up on decision-making. Such research would help us design deliberative mini-publics which will lead to effective and democratic science policies, all the while safeguarding the integrity of science.

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