# UNPACKING SOLAR GEOENGINEERING GOVERNANCE CHALLENGES

A critical interpretative review of the state-of-the-art and implications for the design of anticipatory governance

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Date: 20th March 2024

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# ACKNOWLEDGEMENTS


This thesis is the culmination of six months of dedicated effort, and I am deeply grateful to the individuals who have stood by me throughout this journey.

First, I extend my sincere appreciation to my supervisor, Dr. Aarti Gupta, whose constant support, brilliant insights and kind words of encouragement helped me navigate this challenging path. Her supervision has not only helped me complete this thesis but has also fostered a newfound confidence within me.

I whole-heartedly thank Wageningen University and the amazing people I encountered here. To my AID family and fellow Climate Studies colleagues, your presence has made these past two years a truly enriching experience that I will cherish much in the future. Additionally, to my childhood friends scattered across the globe, I am immensely grateful for your constant support. Emma, Giulia, Lucia, Sonia, Steffanya and Giulia, thank you for gifting me the privilege of your friendship.

Lastly, I would like to express my warm gratitude to my family, particularly my parents, who trusted and supported me in my decision of pursuing my educational journey abroad, and my sister, who is the most important person in my life and greatest source of inspiration.

# ABSTRACT

Weak international mitigation efforts, coupled with rising climate change and destructive extreme weather events, have pushed scientists and innovators toward finding alternative pathways capable of ensuring a resilient future. Among the numerous proposals, solar geoengineering, specifically the idea of injecting aerosols to create a reflective layer around the Earth (stratospheric aerosol injection, SAI), has been brought up in the climate governance discussions and praised as a possible solution. However, the current debate on the prospect of this speculative technology, and its desirability or feasibility, has generated diverse perspectives and contestations, making solar radiation management (SRM) a wicked governance challenge. This thesis endeavor is to unpack the complexity of the solar geoengineering debate by bringing together the state-of-the-art on some of its most controversial or under-analyzed concepts: mitigation deterrence, unilateral deployment and procedural justice. Upon this unpacking, the implications for future governance of solar geoengineering are identified and brought together in the context of anticipatory governance of novel technologies. The results show how the complexity and risks linked with this planetary-changing technology require both further research and immediate governance arrangements to ensure procedural justice and avoid mitigation deterrence and unilateral deployment in solar geoengineering future developments.

**Keywords:** solar geoengineering, SAI, SRM, anticipatory governance, mitigation deterrence, unilateral deployment, procedural justice.

# List of Abbreviations

| | |
|---|---|
| CDR | Carbon Dioxide Removal |
| $CO_2$ | Carbon dioxide |
| CSIGG | Centre for Sustainability Innovation and Good Governance |
| GHG | Greenhouse Gases |
| ILO | International Labor Organization |
| IPCC | Intergovernmental Panel on Climate Change |
| RFF | Resources for the Future |
| SAI | Stratospheric Aerosol Injection |
| SIDS | Small Island Developing States |
| SRM | Solar Radiation Management |
| UN | United Nations |
| UNEP | United Nations Environment Program |
| US | United States |

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# 1 INTRODUCTION

Since the entry into force of the Paris Agreement in 2015, eight years of climate action have taken place. However, the positive effects of states' policies in tackling climate change are modest and insufficient to achieve the ambitious 1.5 °C target (UNEP, 2023). Indeed, “current commitments to future mitigation of carbon dioxide ($CO_2$) emissions are projected to result in warming closer to 3°C” (MacMartin et al., 2018a, p. 2). Additionally, according to the Intergovernmental Panel on Climate Change’s (IPCC) sixth Assessment Report, the world continues to be afflicted by extreme weather events, like severe rainfalls and heat waves, which cause deaths and damage to vulnerable societies and ecosystems, and further exacerbate inequalities between the rich and underdeveloped areas of the globe (Calvin et al., 2023). To reverse this negative trend, the scholarship on climate change is looking for alternative instruments that would be able to address global warming and ensure the achievement of the aspiring Paris Agreement’s targets.

Among these new approaches, one in particular is gaining a lot of attention and heating the debate: geoengineering, the “deliberate large-scale intervention in the Earth’s climate system, in order to moderate global warming” (*Geoengineering the Climate*, 2009, p. 9). It refers to a set of planetary-level technologies, which aim at manipulating the environment to stop further climate change and offset its adverse impacts (Harvard, n.d.). For example, such technologies would be able to absorb the $CO_2$ present in the atmosphere (carbon dioxide removal, CDR), or reduce the warming up of the planet by reflecting back into the space the incoming sunlight (solar radiation management, SRM, or solar geoengineering) (Caldeira et al., 2013). Despite both CDR and SRM techniques presenting several issues, the scope of this research focuses mainly on the problematic concerns arising from solar geoengineering. Among solar geoengineering technologies, the most discussed are space-based reflectors, cirrus cloud thinning, stratospheric aerosol injection and marine-cloud brightening. This thesis concentrates specifically on stratospheric aerosol injection (SAI) as it is the technique that so far has received most of researcher’s attention because of its technical feasibility and potential.


*Figure 1: Solar radiation modification methods* (Reducing the Risks of Climate Overshoot, 2023).

Before diving into more details of what are the critical implications of solar geoengineering, it is worth explaining how the idea of engineering the climate to cool the planet has gained momentum. Firstly, some experts suggest that the proposed implementation of such technologies is relatively cheap if compared to mitigation efforts, and the results are visible already in the short term (Klepper & Rickels, 2014). For example, it was estimated that the yearly expenditure to counterbalance the temperature increase caused by high $CO_2$ concentration through solar geoengineering might be as low as 1 billion US$ (Klepper & Rickels, 2014). Whereas estimated costs of reduced greenhouse gasses (GHG) through mitigation policies range between 1 to 7% of the global GDP (Fujimori et al., 2023). Secondly, solar geoengineering is technically feasible and able to produce a cooling effect. As a matter of fact, among the different types of solar geoengineering technologies, SAI can reduce temperatures by replicating the effect of a volcanic eruption, similar to the "1991 Mount Pinatubo eruption that caused global annual-mean cooling of about 0.3–0.5°C in the following two years" (UNEP, 2023, p. 11). Therefore, it is possible to imagine the degree of attraction towards solar geoengineering research, however, even though climate engineering looks good on paper it presents several issues.

## 1.1 STRATOSPHERIC AEROSOL INJECTION

Stratospheric aerosol injection (SAI) is the solar geoengineering technique that has received the most academic consideration. As said before the idea behind this technology is to simulate a volcanic eruption by emitting a certain quantity of sulfur dioxide, or sulfate aerosol, into the stratosphere, which would produce a reflective layer around the Earth capable of reflecting the sunlight and thus reducing the temperatures. Global-scale SAI projects would likely require a fleet of several aircrafts, similar to the current FedEx fleet, and the volume of flights necessary to sustain such interventions would be comparable to the annual departures from New York JFK airport, with the distinction that the planes would predominantly take off and land on the spot rather than crossing the Atlantic[2]. The initial challenge associated with this SAI method is distributing the aerosols at a precise altitude, ideally between 20-25 kilometers. However, there is not an airplane design currently available to efficiently inject the

[2] Daniele Visioni, RFF Conference panel: *"Biophysical Impact: climatic & non-climatic risks and benefits"* (*Solar Geoengineering Futures*, 2023).

aerosol at this optimal height[3]. According to Daniele Visioni (*Solar Geoengineering Futures*, 2023), the location of particle injections is significantly important, as it will determine the climatic response of SAI[4]. For example, by injecting sulfate dioxide into the northern hemisphere it would preferentially cool down that hemisphere. Therefore, considering the technical and logistical aspects of SAI is fundamental to understanding its feasibility as a climate policy option capable of addressing climatic impacts.

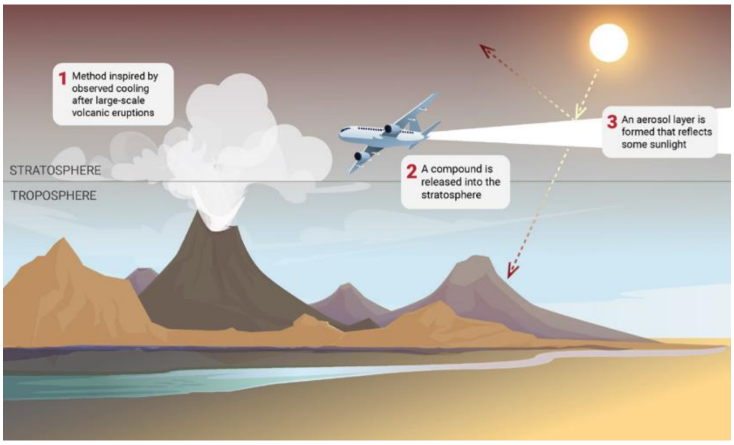



*Figure 2: Stratospheric aerosol injection (One Atmosphere, UNEP 2023).*

Other concerns regarding SAI are the uncertainties over the environmental response of solar geoengineering. Babatunde Abiodun (*Solar Geoengineering Futures*, 2023) recorded how the regional response of African regions is not homogenous, and his study showed how the deployment of SAI would weaken the West African monsoon, reduce precipitation over African tropical areas and destabilize droughts adaptation strategies in the region. On the same line, John Moore (*Solar Geoengineering Futures*, 2023) highlights that implementing SAI in the Arctic regions could sufficiently decrease temperatures to preserve the ice sheet. However, since a substantial portion of global warming is absorbed by the oceans, SAI would not be able to prevent melting caused by warmer ocean temperatures. Additionally, Daniele Visioni (*Solar Geoengineering Futures*, 2023) emphasizes how there are still many unresearched SAI dynamics that require more attention; for example, studies looking at the life cycle of aerosols in the atmosphere, as well as the environmental response associated with the deposition of these, are still lacking. Finally, Lily Xia (*Solar Geoengineering Futures*, 2023) says that SAI can be considered a form of decoupling temperatures from $CO_2$ concentration, creating a

[3] Lili Xia, RFF Conference panel: *"Biophysical Impact: climatic & non-climatic risks and benefits"* (*Solar Geoengineering Futures*, 2023).
[4] Daniele Visioni, RFF Conference panel: *"Biophysical Impact: climatic & non-climatic risks and benefits"* (*Solar Geoengineering Futures*, 2023).

completely new challenge for whole ecosystems as SAI would create a novel environment in which high $CO_2$ emissions are coupled with low temperatures. In addition, once the climate intervention is initiated, deciding on the timeframes and termination of solar geoengineering would present a complex governance challenge, as the abrupt termination of SAI would lead to rapid warming. This problem, also found in literature as ‘termination shock’, is used by scientists to describe SAI and its masking effect to rising temperatures, according to which once the injection is stopped the accumulated heat would be perceived again (Irvine et al., 2016). Therefore, it is fundamental to understand that SAI is no easy technology and its impacts on the environment should not be disregarded but thoroughly evaluated.

## 1.2 PROBLEM STATEMENT

All this considered, what makes solar geoengineering such a particularly controversial topic is the novelty and the current regulatory void of the field. Indeed, because of the absence of specific institutions or policies, and the high stakes and high uncertainties of solar geoengineering, this speculative technology poses intricate anticipatory governance challenges, with geopolitical, ethical, justice and environmental dimensions. For example, the environmental impacts and risks of such manipulation of the climate system are still uncertain and based on models’ outputs (Irvine et al., 2016); from a governance perspective, the decision-making process and the design of new policies represent an uncharted territory (Aldy et al., 2021); finally, questions on how to ensure justice and an ethical deployment remain still unanswered (Stephens & Surprise, 2020). Therefore, before deciding on the use or ban of solar geoengineering, further research and understanding is required, especially in those fields that have so far received less attention in academia, with the final aim of reducing uncertainties and building fair anticipatory governance frameworks for solar geoengineering.

The academic field is highly divided and uncertain of the possible implications deriving from the use of solar geoengineering technologies. Indeed, the debate on solar geoengineering is heated and messy because of expert’s opposing and distant perspectives. On the one hand, some researchers and climate skeptics believe in the potential for solar geoengineering to become the main approach in the fight against climate change. Their claim is based on the “napkin diagram” shown below, according to which the use of solar geoengineering is necessary and crucial to reach the 1.5 target and avoid overshoot. Indeed, the idea behind the graph is that the employment of solar geoengineering, combined with CDR technologies, would be able to compensate for current weak emissions reduction commitments and ensure the accomplishment of the Paris Agreement's targets by peak-shaving global warming trajectories (Asayama & Hulme, 2019).

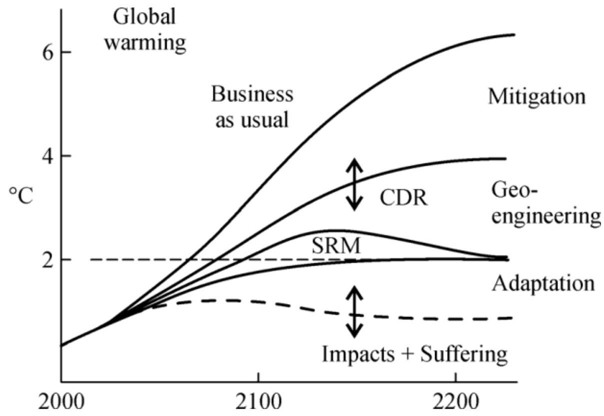



*Figure 3: napkin diagram representing a portfolio approach to climate change (Long & Shepherd, 2014). The diagram shows how only with the inclusion of solar geoengineering is it possible to keep the warming at 2°C.*

On the other hand, scholars strongly oppose the idea of employing solar geoengineering as a technological fix, and they believe that solar geoengineering represents a dangerous alternative that might dim mitigation and adaptation efforts. Indeed, supporters of a more cautious approach argue for the application of such technologies as a last resort opportunity, that requires first strong emissions reduction efforts, governance frameworks, further research, and a thorough evaluation of the risks, before even considering solar geoengineering employment. Thus, experts belonging to this side of the debate usually advocate for the implementation of a moratorium (Reducing the Risks of Climate Overshoot, 2023) or, as recently published, an International Non-Use Agreement (Biermann et al., 2023).

To summarize, the field of solar geoengineering can be considered a sensitive topic that will be at the top of the agenda for researchers involved in climate research. The numerous challenges and risks linked to this new field will require careful evaluation, and they might open a new era for climate governance and international politics.

## 1.3 RESEARCH OBJECTIVE

Solar geoengineering is an emerging theme in the climate change debate that still has numerous uncertainties. Our understanding of how this technology should work, or how its anticipatory governance should look like is rather superficial and, because of experts' multiple perspectives, it is difficult to comprehensively understand solar geoengineering. Thus, due to its wicked nature, solar geoengineering represents a unique anticipatory governance challenge that requires further investigation.

Therefore, this research project is driven by three objectives. First, this thesis endeavor is to analyze the design and feasibility of anticipatory governance of novel technologies with solar geoengineering as a case. Indeed, because of the high uncertainties of solar geoengineering, anticipatory governance represents the most suitable governing framework in such field. Second, it aims to unpack the complexity of the debate around the issue of solar geoengineering by presenting a comprehensive analysis of the state-of-the-art in the solar geoengineering debate in the period from 2010 till now, and this debate can be considered the object of research. Particularly, the thesis focuses on three crucial concepts that frequently occur in academic literature, authoritative assessments and public conferences, which represent important challenges for solar geoengineering's future governance. These concepts are *procedural justice*, *mitigation deterrence* and *unilateral deployment*. Third, by unpacking these core elements of the debate and contestations relating to each, the final objective of this thesis is to identify the implications for future governance of solar geoengineering in these three domains.

## 1.4 RESEARCH QUESTIONS

Given the fact that solar geoengineering might produce adverse effects on ecosystems, biodiversity, societies and people, it is crucial to highlight what the current state of knowledge of solar geoengineering is in order to improve our understanding and allow us to make more informed decisions in the future. The design of anticipatory governance of solar geoengineering technologies requires a deep understanding of the concepts' state-of-the-art as well as their implications in shaping future governance arrangements, Therefore, the overarching research question of this research project is:

RQ: *What are the core contestations in solar geoengineering scholarship and what implications do these have for design and feasibility of anticipatory governance?*

To address this main question, two sub-research question are developed:

SRQ1: *What is the state-of-the-art on contested debates around mitigation deterrence, unilateral deployment and procedural justice in solar geoengineering governance scholarship and policy debates?*

SRQ2: *How can future governance of solar geoengineering navigate the implications associated with ensuring procedural justice, while preventing mitigation deterrence and unilateral deployment, and how feasible is it, also given the uncertainties and diverse perspectives surrounding these pivotal challenges?*

## 1.5 THESIS OUTLINE

To help the reader move through this research project, this roadmap provides a brief overview of the divisions and the main themes. Following this introductory chapter, the conceptual framework is presented to provide the definition of the concepts around which this thesis builds the state-of-the-art of the solar geoengineering debate and the governance implications. The third chapter introduces the research design and the methodology chosen to answer the research questions, in particular highlighting the different data sources and how these are going to be employed throughout the thesis.

Chapters 4 and 5 represent the two empirical chapters answering the sub-research questions cited before. The chapters use a combination of data from the different data sources used in this thesis (scientific literature, conference observation, authoritative assessments). Chapter 4 is dedicated to the state-of-the-art of solar geoengineering in the three focus concepts. Chapter 5 builds on results emerging from Chapter 4 and its endeavor is identifying the governance implications that arise from the tensions in each of the focus concepts of the thesis. Lastly, concluding remarks and a way forward for solar geoengineering are presented in the last part of this research project.

# 2 CONCEPTUALIZING SOLAR GEOENGINEERING AS A CASE OF ANTICIPATORY GOVERNANCE

The novelty of solar geoengineering makes it a compelling object for governance; and especially because these technologies are still in the conceptual stage, they could pose significant challenges of anticipatory governance. Therefore, it is essential to comprehend the implications of solar geoengineering at the governance level, particularly in these early phases. Vital question needs to be addressed to fully understand the realm of solar geoengineering governance. These include, for example, how governance should respond to the challenges of solar geoengineering, which form of governance is the most suitable to tackle these issues, how it is possible to avoid future risks, and how to identify the beneficiaries or potential losers from these technologies. Delving into these questions is fundamental not only for comprehending the field of solar geoengineering, but also for understanding the broader landscape of climate governance. Indeed, considering solar geoengineering as a policy response to climate change, this will significantly influence the global governance approach in addressing this crisis.

In this thesis, governance is broadly conceptualized as in Parker et al. (2018): "all processes of governing, whether undertaken by a government, market or network, whether over a family, tribe, formal or informal organization or territory and whether through laws, norms, power or language' (p. 2). This overarching definition is broad and inclusive enough to consider different actors and not only formal, top-down forms of governance but informal, bottom-up examples as well, which in the novel field of solar geoengineering are equally important and fundamental to consider. In this regard, the concepts under analysis in this thesis represent three key elements in the solar geoengineering governance regime that will most likely determine the form and feasibility of secure, fair and effective future solar geoengineering governance arrangements. Mitigation deterrence, unilateral deployment and procedural justice, with their conceptualizations and challenges rise serious implications for governance that are essential to address. Thus, by highlighting the challenges, controversies and various perspectives in these three concepts the final result is that it is possible to identify the areas in which anticipatory governance should intervene and strengthen its control on solar geoengineering technologies research and deployment.

## 2.1 ANTICIPATORY GOVERNANCE OF NOVEL TECHNOLOGIES

Discussions on solar geoengineering, despite proving to be so controversial, are highly speculative as these technologies are still at the conceptualizing phase and the road to reach a real-world deployment is far away, and it may not even be there. Thus, the current state-of-the-art on solar geoengineering is based on future assumptions and projections upon which current research and decisions are performed producing a *de facto* governance effects (Gupta & Möller, 2019). Therefore, we can frame solar geoengineering within theories of anticipatory governance. As Gupta et al. (2020) emphasize solar geoengineering represent an anticipatory challenge where the boundaries and "the object of governance remain uncertain and largely unknowable" (p. 10). Defined as "a flexible decision framework that uses a wide range of possible futures to prepare for change and to guide current decisions toward maximizing future alternatives or minimizing future threats" (Gupta et al., 2020, p. 11), anticipatory governance provides a useful theoretical lens to place and further understand the different perspectives and contestation around these controversial approaches to the climate crisis.

What does it mean to establish anticipatory governance? Some may argue that anticipation is a core characteristic present in various forms of governance. However, this common interpretation is misleading. Anticipation does not represent a form of precaution or prediction, but rather it entails the establishment of regulatory mechanisms in the present, in anticipation of a future event (W. Foley et al., 2018). So, by applying this mechanism to novel technologies, anticipatory governance tries to govern new technological fields, especially those characterized by high uncertainty, by implementing regulations at present in anticipation of possible future risks. Indeed, according to Cummings & Rosenthal (2018) the anticipatory governance perspective is relevant for the analysis of technologies in the context of climate policies, as they believe its main strengths is its "ability to provide balance between protecting against harmful outcomes and promoting an amenable environment for technological research and innovation" (p. 209). To rephrase, anticipatory governance can anticipate and prevent future risks while enabling careful research in the present. Achieving such goal through anticipatory governance arrangements require certain elements. For example, Oldham et al. (2014) believe that evidence-based foresight, a certain degree of flexibility and an efficient monitoring capacity are among the most common attributes of anticipatory governance; instead, W. Foley et al. (2018) and Guston (2014) lists foresight, engagement and integration as the three main conditions of anticipatory governance; finally, Quay (2010) adds monitoring and response to change as essential elements of anticipatory governance.

Despite being a useful theoretical framework to analyze the governance of novel technologies, the anticipatory approach to governance comes with some limitations. Indeed, "seeking to shape an unknown and largely unknowable future is fraught with normative and scientific uncertainties and conflicts" (Vervoort & Gupta, 2018, p. 104). Guston (2014), by considering a more participatory definition of anticipatory governance, critiques how such governance arrangement might lack a certain degree of participation and, as the definition of imaginaries and futures is likely placed in the hand of scientists involved in technological development, this leaves a considerable share of decision-making power to the epistemic community. Additionally, there is a worry that such governance framework, highly dependent on scientific foresight, might disregard the contribution coming from the social sciences (Guston, 2014). Finally, anticipating decisions in the prospect of future threats might unintentionally lead to prioritize certain futures and disregard other alternatives. This is what Paprocki (2019) calls anticipatory ruination, a term to highlight the tendency of anticipatory governance of considering future destruction as inevitable. Nevertheless, all this considered and despite the mechanisms of anticipatory governance are still developing, anticipatory governance provides a crucial perspective in understanding the role of novel technologies, like solar geoengineering, in the broad climate governance landscape. Especially, if implemented with a close combination of participatory processes, natural and social sciences, anticipatory governance builds the ground "for dialogue and more reflexive decision-making" (Guston, 2014, p. 234) that are necessary in the field of solar geoengineering.

## 2.2 CONCEPTUAL FRAMEWORK

This thesis organizes the debate of solar geoengineering around the three core concepts identified as relevant for future anticipatory governance: mitigation deterrence, unilateral deployment and procedural justice. The concepts were identified through preliminary research of recent scientific literature and reports, as well as by attending a public symposium on solar geoengineering research for decision-making. These concepts represent some of the most discussed, controversial and debated elements of the solar geoengineering debate as they lack a uniform consensus in academia. Thus, these three domains are particularly relevant from a future governance point of view since they present numerous challenges for both scientists and policymakers, and their presence or absence in the solar geoengineering debate might determine the future pathways of this controversial technology. First, solar geoengineering poses questions of how to ensure a procedurally just decision-making process that considers the voices of the most vulnerable actors. Second, the consideration of solar geoengineering as a solution to climate change might increase the risk of mitigation deterrence, shifting the focus away from mitigation. Finally, the absence of specific regulatory frameworks or institutions makes solar geoengineering an opportunity for countries, coalitions of countries, or private actors to unilaterally apply such technologies whether for profit or fear of an increased exposure to the risks of global warming.

As each sub-topic within the geoengineering debate poses its separate and unique challenges, this thesis tries to point out the most important traits, tensions and different perspectives in each one of them to reach a deeper understanding of what is the current state of knowledge in the solar geoengineering debate. In the following sections the core concepts of this thesis are briefly defined and unpacked.

### 2.2.1 Mitigation deterrence

Mitigation deterrence, also found in literature as ‘moral hazard’ or ‘mitigation obstruction’, is one of the main debated concerns in the field of solar geoengineering research, and one of the first arguments to be appealed to when rejecting it. The notion of mitigation deterrence refers to the risk that solar geoengineering might shift individuals’ and policymakers’ focus away from mitigation efforts because it would act as an adequate solution and insurance policy against global warming (Jebari et al., 2021a; Markusson et al., 2018; D. McLaren, 2016). According to Reynolds (2021) mitigation deterrence corresponds to a situation where the protection from insurance, and that feeling of safety, might lead to risky behaviors and decision-making. Thus, solar geoengineering technologies can be considered an insurance policy against the failure of mitigation policies in reaching the 1.5-degree target, “a risk compensation effect, by which knowledge about a remedy to the impacts of a risk lulls people into a reduced fear of that risk” (Raimi et al., 2019, p. 301).

Therefore, given the current insufficient efforts into mitigation, it is striking how mitigation deterrence represents a worrisome concern which should immediately make people think critically about the true value and purpose of solar geoengineering. However, mitigation deterrence remains a vastly contested concept. For instance, in academic debates, scholars have very opposite opinions on the matter. On the one side, some believe that the chance of solar geoengineering halting mitigation efforts is remarkably high, especially in the absence of comprehensive regulations, governance frameworks, or adequate information on the risks that solar geoengineering might produce. On the opposite side, researchers argue there is no evidence that can prove the risk of mitigation deterrence (J. L. Reynolds, 2021) and that solar geoengineering might even increase mitigation ambitions, particularly at the individual level where it is possible to record a so-called "reverse moral hazard" (Burns et al., 2016).

Finally, to conceptualize mitigation deterrence further, it is important to add that authors have been advancing diverse categorizations of the concept, which can differ according to the context and the actors. Corner & Pidgeon (2014) and Hale (2012) identify three levels of a hazard: the individual, the social and the political. Finally, Reynolds (2014) distinguishes an ex-ante and an ex-post moral hazard.

### 2.2.2 Unilateral deployment

After the concept of mitigation deterrence, the risk of unilateral deployment of solar geoengineering technologies is another highly discussed issue in the debate. Indeed, because of the rather cheap costs of solar geoengineering, numerous scholars believe that it would be in the interests and capabilities of a mighty country, or a wealthy individual, to pursue deployment unilaterally against the will of the international community (Surprise, 2020a). In this thesis, unilateral deployment is understood as "the deployment of relevant technologies, at a global scale, by a single state or non-state actor without the (explicit or implicit) consent of the international community" (Rabitz, 2016, p. 100). Additionally, Rabitz (2016) identifies norms, incentives and capacities to procure and maintain these technologies as the main conditions to consider when analyzing the possibility of unilateral action.

For Parker et al. (2018) and Halstead (2018), the issue of unilateral deployment is linked to the argument of the free-driver problem. Regarding the free-driver problem, an actor would be incentivized to deploy solar geoengineering because the benefits outweigh the costs. Additionally, in their views, it is correct to include in the definition of unilateral deployment also an eventual intervention by a coalition of countries, because such a coalition would still not represent the entirety of the international community, thus posing the same threats of an action taken by one individual actor. Finally, according to Fruh & Hedahl (2019), unilateral deployment can also be considered a violation of sovereignty and therefore it might lead to acts of war. By applying the just war theory, the authors try to assess the admissibility of such unilateral action by international law and confirm that, to be considered just, unilateral deployment requires to satisfy the following criteria: legitimate authority, last resort, reasonable hope for success, self-defense and exhibit the right intention and wide proportionality (Fruh & Hedahl, 2019).

### 2.2.3 Procedural justice

"The concept of justice has traditionally been divided into two subtopics: distributive justice, the fairness of the actual division of outcomes; and procedural justice, the fairness of the steps taken in making allocation decisions" (Barrett-Howard & Tyler, 1986, p. 296). In the field of solar geoengineering, the latter concept requires particular attention, since currently there are no instruments that ensure a fair and participatory decision-making process for solar geoengineering.

In Svoboda et al. (2011) view procedural justice is a fair and correct procedure that makes the outcome just in itself, if such procedure is followed. Similarly, according to Holland (2017), procedural justice refers to the "justness of the institutional processes and procedures through which decisions are made" (p. 394). Despite Hollands's definition of procedural justice is applies to the framework of adaptation policies, it is still possible to adapt some of his arguments to the topic of solar geoengineering. Indeed, as for the case of adaptation, climate change policies that do not consider procedural justice during their design or decision-making process fail to address existing structural inequalities and to provide a voice to under-represented vulnerable populations (Holland, 2017). Therefore, a procedural justice approach to solar geoengineering would require a deep consideration of the world's injustices and it would provide marginalized actors the power to participate and protect their interests when decisions on solar geoengineering are being taken. So, when procedural justice is applied an inclusive and just approach of solar geoengineering is achieved and durable, fair and participatory outcomes are obtained.

But how is it possible to ensure procedural justice? By looking at the scientific literature, the criteria and standards that need to be accounted for to ensure procedural justice are numerous. First, for Grasso (2022) it is essential that participation and recognition of the involved agents are ensured in the process. He also adds the criteria and standards to look for, which are: impartiality, equality of opportunity, involvement and knowledge. To this list, it is possible to add the necessity to have a mechanism for appeal and ensure fairness (Tuana, 2018), the all-affected principle (Heyward, 2019; Svoboda et al., 2011; Tuana, 2018), consent (Pamplany, 2020), recognition (Hourdequin, 2019; D. P. McLaren, 2018), transparency and fair representation in the decision-making process (de Ridder et al., 2023; Heyward, 2019).

Thus, procedural justice is about ensuring that each stakeholder has voice and power when decisions that directly affect them are taken.

In summary, in the debate of solar geoengineering the concepts of mitigation deterrence, unilateral deployment and procedural justice represent three critical pillars of solar geoengineering governance, which require further investigation. Therefore, this conceptualization provides an exhaustive definition and framing of each concept, and it represents the starting point of this thesis's research. In the figure below it is possible to graphically visualize the object of this research and its conceptual framework. Future solar geoengineering governance will mostly depend on the development of each concept in the current academic debate on solar geoengineering.

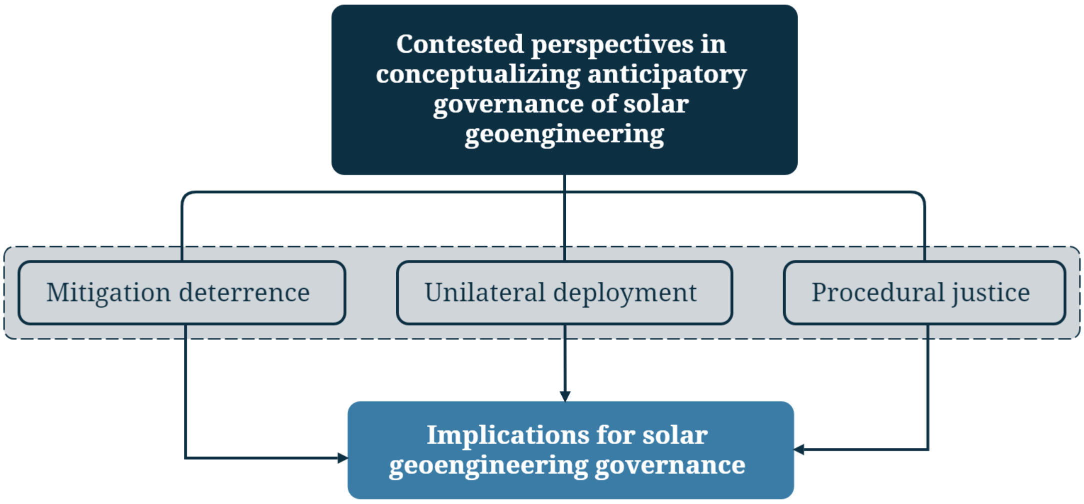



*Figure 4: Conceptual framework: the debate on solar geoengineering, with attention to the different perspectives and contestations, is unpacked into the three focus-concepts of the thesis, which are placed in separate boxes. The arrows starting from these concepts represent the implications for future solar geoengineering governance.*

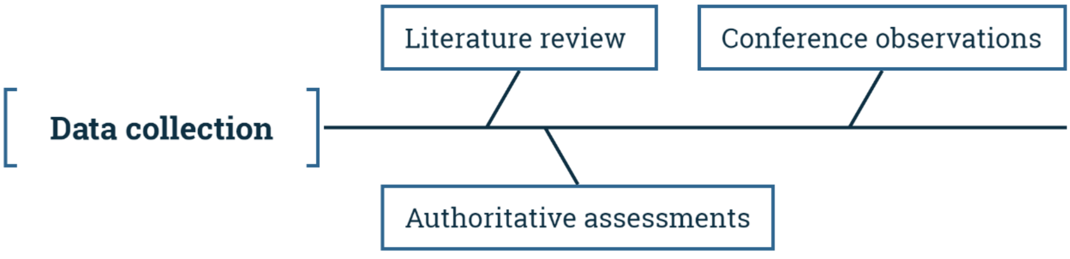
# 3 RESEARCH DESIGN AND METHODOLOGY

## 3.1 RESEARCH APPROACH AND METHODS

This thesis tries to unpack and critically engage with the debate on solar geoengineering. Therefore, this research project employs a qualitative analysis, particularly, a *critical interpretative review* of the state-of-the-art of solar geoengineering. This methodology is employed to interpret the data sources mentioned below, which is particularly relevant for this thesis because it allows to critically evaluate and interpret the different perspectives of the debate on solar geoengineering by highlighting their differences and tensions. This research approach is used as it enables to answer the research questions of this project by identifying the implications and challenges the core concepts present for future solar geoengineering governance. Thus, the research approach and methods of this research project are aimed at exploring the different perspectives in the solar geoengineering debate, by highlighting tensions and contradictions, as well as by providing a contextual understanding including considerations on the historical and cultural influences in the shaping of this speculative technology.

## 3.2 DATA SOURCES

The figure below shows the three steps of the data collection for this research project. First, a literature review is performed; followed by a review of authoritative assessments; finally, primary data are gathered from observation of a public conference on solar geoengineering. These steps are used to analyze the object of analysis, the debate on solar geoengineering and to answer the research questions of this thesis.



### 3.2.1 Literature review

In the academic world, the debate on solar geoengineering is characterized by a consistent load of research coming both from the social and natural sciences. On the one hand, the contribution from the social sciences is essential to provide just and fair solar geoengineering research that considers the social, economic and political implications of solar geoengineering. On the other hand, life sciences scholars help deepen our understanding of solar geoengineering's technicalities and effects on the environment. This variety of experts and academics trying to understand the possible positive or negative impacts of solar geoengineering on our societies and ecosystems make this new field quite overwhelming due to the different perspectives and contestations. Therefore, through a literature review of academic papers published between 2010 and 2023 represents the first step of the research. This review aims to gain a first-hand understanding of the state-of-the-art of the solar geoengineering debate, and it helps spotting the underlying meanings, themes and patterns within the literature. Relevant literature is identified through a search by keyword in "Scopus" (the list of keywords is presented below) and the findings from this research are used to build a comprehensive review of the current debate on solar geoengineering in academia.

- "Mitigation deterrence" – "deterrence" – "moral hazard".
- "Unilateral deployment" – "unilateral".
- "Procedural justice" – "justice" – "decision-making" – "procedural" – "developing countries" – "inclusivity" – "indigenous" – "indigeneity" – "Global South".

### 3.2.2 Authoritative assessments

Solar geoengineering has recently gained momentum, and this year many governmental or independent organizations released reports assessing and evaluating solar geoengineering. The diffusion of such reports by high-level institutions is particularly relevant in the field of solar geoengineering governance. Indeed, according to Gupta & Möller (2019) these documents fall into the category of *authoritative assessments* which by their nature represent, or might represent in the future, sources of de facto governance. According to their definition, authoritative assessments are "expert-led, multi-author assessments produced by eminent scientific bodies advancing state-of-the-art understandings of novel and politically contested environmental and technological fields" (Gupta & Möller, 2019a, p. 481) Therefore, gathering secondary data from these reports is one of the data collection steps used in this thesis, which is useful to grasp the debate on solar geoengineering from the point of view of important organizations.

The assessments are identified following two criteria: (1) the type of institution issuing the report (only high-profile institutions are considered, e.g. governmental bodies, international organization, research centers); (2) reports published between 2020 and 2023, this timeframe is set to select only recently published and up to date information. By following these criteria, nine authoritative assessments are identified as they satisfy both chosen criteria (these are listed below). Out of this group of assessments, six are published this year, which is a considerable amount if compared to the previous years (one per year in 2020, 2021, 2022). Thus, this trend shows how political and scientific institutions are developing an increasing interest in understanding more in-depth solar geoengineering technologies and their social, economic, political and environmental implications. Relevant data within these reports is identified through a search by keywork, then paragraphs relating to each concept are taken and compiled in an Excel file. Subsequently, a critical interpretative review is performed to build a comprehensive understanding of the state-of-the-art in each focus concept of this thesis (procedural justice, mitigation deterrence, unilateral deployment). The search by keyword did not produce results in the authoritative assessments under analysis because they employ a different terminology or the concepts' presence is implicit throughout the report, therefore a more-in-depth identification is required and performed.

- Florin et al. (2020) – *"International governance issues on climate engineering – information for policymakers".*
- National Academies of Science (2021) – *"Reflecting sunlight: recommendations for solar geoengineering research and research governance".*
- Felgenhauer et al. (2022) – *"Solar radiation modification: a risk-risk analysis".*
- Centre for sustainability innovation and good governance (CSIGG) (2023) – *"Geoengineering report – policy, research, technology and the future".*
- European Commission (2023) – *"Scoping paper: solar radiation modification".*
- UNESCO (2023) – *"Draft report of the world commission on the ethics of scientific knowledge and technology (COMEST) on the ethics of climate engineering".*
- UNEP (2023) – *"One atmosphere: an independent expert review on solar radiation modification research and deployment".*
- Climate Overshoot Commission (2023) – *"Reducing risks of climate overshoot".*

- Office of science and technology policy (OSTP) (2023) – *“Congressionally mandated research plan and an initial governance framework related to SRM”.*

### 3.2.3 Conference observations

Finally, observations from a two-day conference (18-19/10/2023) organized by Resources for the Future (RFF), an independent and non-profit research institute in Washington DC (USA), are used to collect primary data to answer the research questions. The public symposium, with the title *Solar geoengineering futures: interdisciplinary research to inform decision-making*, gathered eminent researchers and experts in the field to explore the big questions of solar radiation management research and decision-making. Conference panels:

- Panel 1 | Biophysical impacts: Climatic and non-climatic risks and benefits
- Lunch | A conversation with Right Honorable A. Kim Campbell, P.C.
- Panel 2 | Would solar geoengineering crowd out emissions cuts? The moral hazard risk examined
- Panel 3 | Solar geoengineering’s place within the broader climate strategy portfolio
- Pnale 4 | Plausible non-optimal near-term solar geoengineering scenarios
- Panel 5 | Capacity building for competent, just, and inclusive decision making
- Lunch | Conversation on the NOAA Earth radiation budget with Gregory Frost
- Panel 6 | Important next steps for policy and research: a solar geoengineering research agenda for the next decade.

Data were gathered by reading the transcriptions[5] of the conference’s panels and by pointing out the most relevant information to each research question. Additional data were also identified by analyzing the panelists’ answers to the questions that came from the audience. Overall, most of the discussions focused on three main concepts that happen to be also the central themes of this research project. First, the panel “*Would solar geoengineering crowd out emissions cuts? The moral hazard risk examined”* centered on analyzing the risk or mitigation deterrence. Second, deployment scenarios were discussed in the panel “*Plausible non-optimal near-term solar geoengineering scenarios”*. Third, the panel *“Capacity building for competent, just, and inclusive decision making”* addressed questions on how to ensure justice in the solar geoengineering decision-making process. Additional important considerations on procedural justice, mitigation deterrence and unilateral deployment were also found in the other

[5] Generated using Good Tape®, an AI tool, and checked for correctness by the author of this thesis.

panels. However, a shortcoming that is worth mentioning is that, despite concentrating a lot of the discussions on the role of the Global South, no attention was given on indigeneity and the role of Indigenous people, which is a central theme for climate governance that should be addressed.

## 3.3 DATA ANALYSIS

This thesis employs a *critical interpretative review* of the state-of-the-art of solar geoengineering. The inspiration for this data analysis approach was taken from the paper by Muiderman et al. (2020), entitled "*Four approaches to anticipatory climate governance: different conceptions of the future and implications for the present*", in which the authors, in analyzing the concept of anticipatory governance, introduce the interpretative review as a research methodology. Considering that an interpretative approach allows to detect how experts and organizations understand, use or frame certain concepts in scientific debates (Muiderman et al., 2020), the same approach can be applied for the unpacking of the concepts of mitigation deterrence, unilateral deployment and procedural justice in the solar geoengineering debate. Indeed, Muiderman et al. applied the interpretative review to identify the diverse perspectives on anticipatory governance and, as done in this thesis, used a search by keyword to select the literature explicitly dealing with their object of research. As a result, this methodology can help build a representative sample of the state-of-the-art in the scholarship of solar geoengineering. Lastly, the critical interpretative review framework allows to "critically interrogate and broadly map diverse perspectives on an important phenomenon in the study and practice of sustainability" (Muiderman et al., 2020, p. 4) without setting strict research boundaries.

# 4 UNPACKING THE SOLAR GEOENGINEERING DEBATE

This empirical chapter answers the first sub-research question of this thesis: *what is the state-of-the-art on contested debates around mitigation deterrence, unilateral deployment and procedural justice in solar geoengineering governance scholarship and policy debates?* (SRQ1). To build a comprehensive reconstruction of the state-of-the-art in the solar geoengineering debate each of the core concepts of this thesis are individually scrutinized. In this way it is possible to truly comprehend their main characteristics, challenges and perspectives, and consequently place them in the solar geoengineering debate. In the chapter the concepts appear in the following order: mitigation deterrence, unilateral deployment and procedural justice.

## 4.1 MITIGATION DETERRENCE

> *"Solar geoengineering requires thinking and modelling, when things get bad, we cannot just say bring the planes out and solve every problem. If people start to think about it as an excuse not to cut emissions it is a disaster"*- Former Canadian Prime Minister Kim Campbell.[6]

The risk of solar geoengineering technologies reducing mitigation efforts is one of the most debated concern in the solar geoengineering debate and also one of the most worrisome, as the consequences of reduced mitigation due to climate engineering would be catastrophic for the environment (e.g., increased ocean acidification) and would force us to depend even more on solar geoengineering, exposing to future termination shocks (Felgenhauer et al., 2022). However, despite the urgency of the matter, the state-of-the-art on this topic is sharply divided between those who believe that mitigation deterrence should not be a reason to worry or delay solar geoengineering research and development (see: Austin & Converse, 2021; Cherry et al., 2021; Merk et al., 2016; Morrow, 2014; J. Reynolds, 2015); and on the other hand, those who are convinced that deterring mitigation efforts through solar geoengineering is a real, plausible scenario that needs to be prevented at all costs (Corner & Pidgeon, 2014; Halstead, 2018; Markusson et al., 2018; D. McLaren, 2016; Raimi et al., 2019; *Reflecting Sunlight*, 2021). Therefore, it is striking how the two sides of the debate are vastly different and disagreement will probably persist. Therefore, the following sections of this first empirical chapter does not have the ambition to look for an agreement, but rather to categorize these diverse and contested

[6] RFF Conference panel: "*A Conversation with the Climate Overshoot Commission*", (*Solar Geoengineering Futures*, 2023)

views because they will likely determine the design of governance arrangements to prevent mitigation deterrence. In this regard, the main findings relating to mitigation deterrence deal with scales, frames and perceptions, and logics of substitution.

Before diving into the main findings on this concept, this paragraph shortly provides a surface-level contextualization from the three data sources used. First, the authoritative assessments analyzed reflect this divide of the debate as their approaches to the topic of mitigation deterrence are quite different. Indeed, out of the nine authoritative assessments under consideration, five reports acknowledge the risks of mitigation deterrence (CSIGG, 2023; Felgenhauer et al., 2022; *Reflecting Sunlight*, 2021; Florin et al., 2020), whereas four others do not refer to mitigation deterrence or they simply mention the problem without further analyzing the implications of solar geoengineering as a substitute of mitigation (EU, 2023; OSTP, 2023; Reducing the Risks of Climate Overshoot, 2023; UNEP, 2023; UNESCO, 2023). As far as the second data source is concerned, the RFF Conference also extensively examined the issue of mitigation deterrence. Particularly, the conference had a whole panel dedicated to mitigation deterrence ("*Would solar geoengineering crowd out emissions cuts? The moral hazard risk examined"*) in which the panelists introduced the challenges emerging from deterring mitigation as well as the implications for governance. Finally, among the scientific literature, twenty academic papers (listed below) have been identified as dealing with mitigation deterrence. Even though most of them still use the incorrect term of moral hazard they are included anyway in the data analysis as the results published are equally relevant for assessing the state-of-the-art on mitigation deterrence.

| **Mitigation deterrence** | | |
|---|---|---|
| Author | Date | Title |
| Benjamin Hale | 2012 | "The world that would have been: Moral hazard arguments against geoengineering" |
| Jesse Reynolds | 2014 | "A critical examination of the climate engineering moral hazard and risk compensation concern" |
| David R. Morrow | 2014 | "Ethical aspects of the mitigation obstruction argument against climate engineering research" |
| Corner & Pidgeon | 2014 | "Geoengineering, climate change skepticism and the 'moral hazard' argument: an experimental study of UK public perceptions" |
| Duncan & McLaren | 2016 | "Mitigation deterrence and the 'moral hazard' of solar radiation management" |
| Burns et al. | 2016 | "What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for future research" |
| Merk et al. | 2016 | "Knowledge about aerosol injection does not reduce individual mitigation efforts" |
| Markusson, McLaren & Tyfield | 2018 | "Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs)" |
| John Halstead | 2018 | "Stratospheric aerosol injection research and existential risk" |

| | | |
|---|---|---|
| Clare Heyward | 2018 | "Normative issues of geoengineering technologies" |
| Raimi et al. | 2019 | "Framing of geoengineering affects support for climate change mitigation" |
| Austine & Converse | 2021 | "In search of a weakened resolved: Does climate-engineering awareness decrease individuals' commitment to mitigation? |
| Cherry et al. | 2021 | "Does solar geoengineering crowd out climate change mitigation efforts? Evidence from a stated preference referendum on a carbon tax" |
| Jebari et al. | 2021 | "From moral hazard to risk-response feedback" |
| Bodansky & Parker | 2021 | "Research on solar climate intervention is the best defense against moral hazard" |
| Andrews, Delton & Kline | 2022 | "Anticipating moral hazard undermines climate mitigation in an experimental geoengineering game" |
| Cherry et al. | 2022 | "Climate cooperation in the shadow of solar geoengineering: an experimental investigation of the moral hazard conjecture" |
| Wagner & Zizzamia | 2022 | "Green moral hazards" |
| Harding, Belaia & Keith | 2022 | "The value of information about solar geoengineering and the two-sided cost of bias" |
| Jesse Reynolds | 2022 | "Linking solar geoengineering and emissions reductions: strategically resolving an international climate change policy dilemma" |

### 4.1.1 Mitigation deterrence depends on and varies according to different levels

From the literature and the authoritative assessments analyzed it is possible to see that the presence of mitigation deterrence and the degree to which it represents a critical concern varied according to distinct levels. Therefore, differentiating the different scales involved in the solar geoengineering debate is essential to really understand the risks of solar geoengineering deterring mitigation. In this regard, it is useful to refer to Corner & Pidgeon (2014), the first in the solar geoengineering debate who have pushed forward the idea of separating the three levels of mitigation deterrence (in the paper found as 'moral hazard'). In their view:

> "There are multiple levels on which a geoengineering moral hazard might operate. First, the prospect of geoengineering could cause individuals to curb voluntary efforts to reduce carbon emissions. […] If geoengineering were perceived by the public as offering a license to continue carbon-intensive lifestyles, the 'rebound' associated with geoengineering technologies could be even more significant. This behavioral version of the problem might be termed an individual moral hazard. […] Second, people might perceive others to be vulnerable to the moral hazard of geoengineering. That is, a particular individual may not believe that geoengineering policies represent a reason for acquiescing on low carbon commitments but may see a risk that others would modify their attitudes and behaviors. Social norms specifying the urgency of preventative climate policies could shift. This version of the problem might be termed a social moral hazard. Finally, at a political level, resources might be diverted away from mitigation and adaptation efforts. Rhetorical (and more importantly) financial support for existing climate policies could decline. This version of the problem might be termed a political moral hazard" (Corner & Pidgeon, 2014, pp. 2–3).

Therefore, the problem of mitigation deterrence assumes different connotations according to the individual, social and political scale. And it is particularly in the last scale, the political one, where our attention should be directed given the global scope of solar geoengineering and the fact that it is unlikely to see people with their own technology injecting aerosols into the stratosphere. Nevertheless, a lot of academic attention has been placed on assessing the individual level of mitigation deterrence, and experts' results point towards disproving the assumption that solar geoengineering technologies threaten mitigation efforts (Andrews et al., 2022; J. Reynolds, 2015), and identify a reverse trend, in which the prospect of solar geoengineering increases concerns for climate change and support for mitigation (Austin & Converse, 2021; Cherry et al., 2021; Merk et al., 2016).

For example, the first attempt to empirically evaluate the presence of mitigation deterrence was undertaken by Merk et al. (2016). Their study aimed to uncover evidence of individuals' tendency to engage in less mitigation efforts when faced with the prospect of SAI as a mean to reduce climate risks. The experiment, manly focused on individuals with German nationality, found people do not reduce mitigation efforts once exposed to solar geoengineering information, on the contrary the willingness to mitigate might increase, especially if compared to people who are ignorant on the technology. On the same line, Cherry et al. (2021), in assessing the individual level of mitigation deterrence, focus on the perceptions of the US public and highlight how providing information on solar geoengineering does not lead to crowding-out from mitigation, instead it increases the support for carbon taxes. Similarly, Andrews et al. (2022) used an economic game to simulate a decision-making setting on solar geoengineering between lay citizens and policymakers and test the presence of mitigation deterrence. The results from the simulation games show again the same conclusion, rejecting the argument that people would decrease support for mitigation. A final example analyzing people support for mitigation in front of the prospect of solar geoengineering (again in a sample representing U.S. adults) comes from Austin & Converse (2021). In their paper they focused on solar geoengineering technology awareness and designed eight different experiments to find evidence of mitigation deterrence in which the participants read popular media or science articles. The results produced no evidence of mitigation deterrence, confirming how knowing about solar geoengineering did not threaten people's supports for mitigation. As a result, this evidence, rejecting the mitigation deterrence argument, has prompted experts to caution against using it as a rational to disregard solar geoengineering (Bodansky & Parker, 2021; J. Reynolds, 2015), and to express worry about imposing a moratorium on solar geoengineering research

(Morrow, 2014). Nonetheless, while the various examples listed above may suggest dismissing mitigation deterrence due to its undetectability at the individual level, it does not imply that it ceases to be a concern at other scales. Indeed, the National Academies of Science report (2021) states that even if there are studies that show how the moral hazard argument does not apply to the individual level, it is still not a strong enough argument to push forward, because policymakers, countries, or actors with vested interests might act differently than individuals (*Reflecting Sunlight*, 2021). An additional limitation to these studies is that the samples used to build their arguments are not representative of a real-world setting. First, they mostly focus on people's perspectives and behaviors coming from the Global North, and second, do not include actual policymakers as their participants. Thus, the fact that we cannot see mitigation deterrence at the individual level does not inform us about the actual risks of solar geoengineering deterring mitigation or how future decision-making might react to it; and this still represent a small portion of the debate.

Consequently, when dealing with mitigation deterrence, we should move on from individual claims and focus on policymakers' behaviors and perceptions of the technology[7]. Hence, more attention should be placed on assessing the social or political level of mitigation deterrence. However, in the state-of-the-art only one study could be found on this matter, confirming the still marginalized place of this collective levels of mitigation deterrence in the solar geoengineering debate. The paper by Cherry et al. (2023) attempts to overcome the individual level and analyze the collective implication of mitigation deterrence; their results based on a public-good game, where to a group of people is presented the choice to mitigate or deploy solar geoengineering, do not support the mitigation deterrence argument. However, this again represents another example of a controlled environment experiment that is not representative of the complexities of the real world. Ruling out the possibility of diminished mitigation at the political level based solely on one empirical experiment is insufficient and may lead to misleading conclusions. Therefore, it is imperative to conduct additional research to comprehend whether mitigation deterrence is present or absent. Overall, empirically studying mitigation deterrence is not an easy task, especially because solar geoengineering is not deployed in the real world and therefore most of the arguments around solar geoengineering are hypothetical and based on assumptions. "This perhaps explains the mixed findings on

[7] David Morrow, RFF Conference panel: *Would Solar geoengineering Crowd Out Emissions Cuts? The "Moral Hazard"*, (*Solar Geoengineering Futures*, 2023).

citizens' propensity for moral hazard, [and] without live technology, we cannot know what elites will actually do with it" (Andrews et al., 2022, p. 2).

### 4.1.2 Mitigation deterrence is a matter of framings and perceptions

Solar geoengineering introduces a novel field of climate governance, one that the public has not yet fully embraced or engaged with. This unfamiliarity and lack of awareness of the technology makes framings so important in the field of solar geoengineering and mitigation deterrence (Burns et al., 2016; Raimi et al., 2019). Indeed, because the perceptions on solar geoengineering are still not fully developed, the way solar geoengineering is framed influence public's perception of the technology and the presence or absence of mitigation deterrence (Burns et al., 2016). Thus, "without pre-existing perceptions of geoengineering to guide them, people are likely to be swayed by their first exposure to the topic" (Raimi et al., 2019, p. 311).

The National Academies of Science (2021) report further highlights how mitigation deterrence is a problem of framings, and this argument comes out frequently in the data collected. For example, if solar geoengineering is presented as the unique solution and approach to climate change, then the risk of shifting the attention away from mitigation is greater than with the application of more moderate framings (*Reflecting Sunlight*, 2021), or through the linkage of solar geoengineering with other policies like mitigation and adaptation (Felgenhauer et al., 2022; J. L. Reynolds, 2022). The Centre for Sustainability Innovation and Good Governance (CSIGG) report (2023) adopts a similar point of view, emphasizing variations in framing in respect to the category from which the information on solar geoengineering is coming. For example, the media or some scientists might try to highlight the risks and downplay the benefits to avoid mitigation deterrence or do the opposite to present solar geoengineering as a viable option (CSIGG, 2023). Finally, experts at the RFF Conference link the problem of mitigation deterrence to people's perception of climate change risks. Indeed, according to the panelists, the level of agreement over the importance of mitigation measures is determined by the impacts of global warming and on how people perceive them: the worst are the impacts, the more people are willing to spend on mitigation or even on riskier options (*Solar Geoengineering Futures*, 2023).

On this important role of framings influencing solar geoengineering technology perceptions and mitigation deterrence, the paper by Raimi et al. (2019) lists the three main framings used in the solar geoengineering debate: the 'major solution' frame, the 'disaster' frame, and the 'minor solution' frame. Each of these three "storylines" relate to different perceptions of solar geoengineering, to diverse approaches in tackling climate change and to different degrees of mitigation deterrence. First, the major solution frame is something that according to Raimi et al. would resonate with the perspective of technological enthusiasts and some policymakers as it frames solar geoengineering as a techno-fix and inexpensive solution to climate change. Second, the disaster frame portrays solar geoengineering as a dangerous solution that should not be pursued. Finally, in the minor solution frame solar geoengineering is considered a buy-time resolve to pursue while decreasing greenhouse gas emissions. According to the authors, the first two framings are the most problematic ones (Raimi et al., 2019). Solar geoengineering as a major solution would lead people into thinking that solar geoengineering is the solution to all our problems and, as a result, it would reduce support for mitigation. The disaster frame, instead, is even more dangerous because it could spread the idea that by considering solar geoengineering we might have run out of options, and people would completely disengage from acting against climate change. This leaves us with the minor solution framework, which according to the authors is the framing that would reduce, but not completely prevent, the risk of mitigation deterrence. That being said, Raimi et al. (2019) contribution is extremely helpful in understanding how a solar geoengineering frame might lead to the emergence of mitigation deterrence. Presenting solar geoengineering as a techno-fix solution that would allow us to protect ourselves from the impacts of climate change, like the major solution frame, has a high chance of leading to a decrease in mitigation efforts, confirming how the different combination of frames and perceptions of solar geoengineering results in mitigation deterrence.

Worldviews are another factor upon which mitigation deterrence might depend. According to Cherry et al. (2021) "worldviews shape people's perception of risk and support for related policies" (p. 3) and they highlight how attitudes towards solar geoengineering might be influences by cultural factors. In the literature, experts have underlined the fact that solar geoengineering does not go against individualistic and economically liberal views. For example, Cherry et al. (2021) confirms how individuals with individualistic values usually downplay environmental and technological risks, whereas egalitarian and communitarian individuals are more inclined to recognize these risks and properly regulate them. In their paper they find how this second group of more socially concerned individual tend to increase support for mitigation facing the prospect of solar geoengineering. Another example, is given by Corner & Pidgeon (2014) where they say: "people who consume more may be more inclined to view geoengineering as a reason to avoid personal-level behavioral changes than people who consume less" (p. 11). This also links with the fact that mitigation deterrence is more visible in the fossil fuels industry rather than in any other actor category (CSIGG, 2023), suggesting to avoid any manipulation of the discussions by vested interests (Reducing the Risks of Climate Overshoot, 2023). Therefore, understanding the influence that worldviews have on the attitudes towards solar geoengineering is crucial, especially as solar geoengineering technologies are becoming more prominent in the field of climate governance and climate intervention research.

### 4.1.3 Avoid logics of substitution

An effective measure to counter the emergence of mitigation deterrence involves avoiding substitution logics. As McLaren (2016) pointed out "if solar geoengineering perfectly substituted mitigation, then there would be no moral hazard" (D. McLaren, 2016, p. 597). However, it is not rare to see arguments against mitigation deterrence using economics of substitute theories. Thus, it is crucial to recognize that mitigation and solar geoengineering are imperfect substitutes, yielding substantially different outcomes (D. McLaren, 2016). Indeed, despite sharing the overarching goal of halting global warming, mitigation and geoengineering employ different methods and produce different results. While solar geoengineering relies on blocking incoming sunlight radiation, mitigation tackles the root cause of global warming, the high concentration of GHG. Therefore, dismissing the mistake of considering solar geoengineering and mitigation as perfect substitutes is vital to prevent the risk of mitigation deterrence. On this the authoritative assessment published by UNEP stresses the fact that solar geoengineering "does not eliminate the need to decarbonize the energy system or address other GHG emissions […]; hence solar geoengineering should not be viewed as the main policy response to climate change" (*UNEP*, 2023, p. 4). By this the report tries to convey the idea that solar geoengineering on the one hand, and mitigation and adaptation strategies on the other hand, are not mutually exclusive and policy makers should be cautious to not fall into this trap. In this regard, authors like Jebari et al. (2021) have highlighted how mitigation deterrence represents a complex framework of analysis and advocated to adopt different approaches when evaluating different climate policies, such as the "risk-response feedback" concept. According to this approach, mitigation deterrence is not framed as a trade-off between mitigation and solar geoengineering, instead climate change policy options are evaluated together, delineating different pathways that take into account both social and environmental parameters (Jebari et al., 2021a). In their opinion, the solar geoengineering debate should be reframed "to reflect the realities of the climate crisis as it currently stands" (Jebari et al., 2021a, p. 3), where it is impossible to understand in isolation the risk and benefits of a policy option.

In summary, despite numerous scientific papers and authoritative assessments explicitly contesting solar geoengineering as a substitute for mitigation, there persists to be a reluctance to acknowledge the associated risks of mitigation deterrence. Instead, the focus seems to center on disproving such arguments. This resistance becomes evident in the ongoing solar geoengineering debate, as exemplified by Markusson et al. (2018), who state that "informing policymakers that solar geoengineering should only be seen as a supplement rather than a substitute for mitigation is unlikely to be sufficient to avoid harm from mitigation deterrence" (p. 7). Similarly, at the RFF Conference it was stressed that "as the technologies become closer to a substitute of mitigation, and we reach a level where we need mitigation no doubt, anything that kind of lowers that incentive here and now is clearly bad"[8]. Hence, the disproportionate focus on disregarding concerns about mitigation deterrence, coupled with the strive on gathering evidence against it, suggests the presence of problematic dynamics in the solar geoengineering debate, and this confirms the necessity to avoid substitution logics when addressing the complexities associated with mitigation deterrence.

## 4.2 UNILATERAL DEPLOYMENT

After mitigation deterrence, another area of debate in the field of solar geoengineering revolves around unilateral deployment. Consequently, the following paragraphs aim to assemble the state-of-the-art in the field of solar geoengineering technologies deployment. Within this context, the authoritative assessments analyzed mostly concentrate on the consequences arising from unilateral deployment, offering insights into the actions necessary to prevent some of the adverse outcomes of unilateral deployment. The RFF Conference also placed significant attention on unilateral deployment. Especially deployment scenarios were analyzed in the panel *"Plausible non-optimal near-term solar geoengineering scenarios"*, as well as throughout the whole conference, shaping a clear picture of how solar geoengineering technology deployment could play out. This comprehensive overview of solar geoengineering technology deployment was further complemented by the analysis of nine scientific papers (listed below), providing useful understandings and insights of unilateral deployment.

| **Unilateral deployment** | | |
|---|---|---|
| Author | Date | Title |
| Joshua B. Horton | 2011 | "Geoengineering and the myth of unilateralism: pressures and prospects for international cooperation" |
| Florian Rabitz | 2016 | "Going rogue? Scenarios for unilateral geoengineering" |

[8] David McEvoy, RFF Conference panel: *"Would solar geoengineering crowd out emissions cuts? The moral hazard risk examined"* (*Solar Geoengineering Futures*, 2023)

| | | |
|---|---|---|
| Parker, Horton & Keith | 2018 | "Stopping solar geoengineering through technical mean: a preliminary assessment of counter-geoengineering" |
| John Halstead | 2018 | "Stratospheric aerosol injection research and existential risk" |
| Chalecki & Ferrari | 2018 | "A new security framework for geoengineering" |
| Fruh & Hedahl | 2019 | "Climate change is unjust war: geoengineering and the rising tides of war" |
| Kevin Surprise | 2020 | "Geopolitical ecology of solar geoengineering: from a 'logic of multilateralism' to logics of militarization" |
| Axel Michaelowa | 2021 | "Solar radiation modification – a silver bullet climate policy for populist and authoritarian regimes" |
| Holly Jean Buck | 2022 | "Environmental Peacebuilding and Solar Geoengineering" |
| Sovacool, Baum & Low | 2023 | "The next climate war? Statecraft, security, weaponization in the geopolitics of a low carbon future" |

### 4.2.1 Geopolitical implications of altering the climate

Geopolitical concerns are among the most common findings when studying unilateral deployment because an uncoordinated application of solar geoengineering technologies might exacerbate international tensions and lead to conflicts between countries, altering the international order (Felgenhauer et al., 2022; Florin et al., 2020; UNEP, 2023). Particularly, experts stress the fact that any SAI deployment would produce global impacts on the climate system, and no country would be able to restrict the cooling to their own borders[9]; any intervention into the atmosphere is global in nature and interconnected with other processes and impacts, so solar geoengineering effects will be perceived by everyone[10]. Therefore, global rivalry should be avoided at all costs as decisions on solar geoengineering will likely concern every country and person on the planet. In addition, the incentives to deploy solar geoengineering, to show the international community and competing countries that one is affecting the climate, will most likely increase in the future at a faster rate than solar geoengineering governance or regulations, making solar geoengineering a geopolitical threat[11]. Also, unexpected alliances or partnerships might create instability and security risks and escalation dynamics[12]. For example, a hypothetical small-state coalition with India, Pakistan, Brazil and Nigeria, might attempt deployment, and even if it is regional and small, it would still generate a reaction from other countries, causing geopolitical instabilities or start

[9] Lily Xia, RFF Conference panel: "*Biophysical Impacts: Climatic & Non-climatic Risks and Benefits*" (*Solar Geoengineering Futures*, 2023)
[10] Ibid.
[11] Erin Sikorsky, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)
[12] Erin Sikorsky, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)

rivalries[13]. Finally, some experts find that misinformation and misinterpretation of solar geoengineering represent an equally dangerous geopolitical concern when it comes to solar geoengineering deployment[14].

Among these frequent geopolitical concerns there is also the question whether deployment of solar geoengineering answers to logic of multilateralism or unilateralism. Indeed, some experts reject the idea that solar geoengineering technologies could be deployed unilaterally (Halstead, 2018; Horton, 2011; Rabitz, 2016). According to Horton (2011) "SAI geoengineering is ruled not by the threat of unilateral deployment, but rather by a "logic of multilateralism" (p. 63). This can be explained by looking at the nature of the international system, composed by multiple, competing nation-states in which "any country that embarks on unilateral implementation will soon find its efforts frustrated by rivals and friends alike, whose actions across the entire policy spectrum are inextricably linked via the global climate system" (Horton, 2011, p. 63). Therefore, a successful and sustained solar geoengineering deployment, capable of affecting the climate, would inevitably require some sort of international cooperation, leading to forms of multilateral negotiation processes (Rabitz, 2016).

Furthermore, the possible retaliation mechanisms following an uncoordinated solar geoengineering deployment would be enough to discourage such attempts (Halstead, 2018). For example, Horton (2011) believes that costs coming from economic sanctions, diplomatic isolation, or even the threat of the use of force, are sufficient to prevent unilateral deployment. However, from what emerged at the RFF Conference this is a rather weak argument for two main reasons. First, surprisingly enough, according to the panelists there would be no reaction from the international community to a first attempt of unilaterally engineering the climate system[15]. This can be linked to the fact that the effects of solar geoengineering are still uncertain, and it would be in countries' interest to apply a wait-and-see approach before responding because the intervention might not have produced any change, and it might be not worth it to upset the current geopolitical order[16]. Second, "any type of international response to unilateral action does not have a firm basis in international law as the legal status of SAI is

[13] Joshua Horton, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)
[14] Erin Sikorsky RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)
[15] Elizabeth Chalecki, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)
[16] Ibid.

ambiguous and no enforcement measures are explicitly provided for" (Rabitz, 2016, p. 105). Additionally, due to the voluntary nature of international law frameworks, sovereign states cannot be restrained, and so they will have the freedom to decide whether to deploy unilaterally or cooperate in the international system[17].

A contrasting opinion is proposed by Surprise (2020), who believes that solar geoengineering is equally motivated by 'logics of militarization" and that unilateral deployment is a possible scenario. In his analysis, Surprise (2020) looks at the role of the U.S. and how the perception of climate change as a national security threat makes SAI a strategic asset to pursue to maintain the U.S. hegemonic position in the international arena, as well as the American economic power deriving from the fossil fuels industry. Therefore, "solar geoengineering and the geopolitical ecologies of climate intervention are immanent to the structures of global capitalist geopolitics and intimately bound up with questions of world hegemony, control of energy, financial flows, and military-imperial dominance" (Surprise, 2020a, p. 229), a consideration that usually lacks in arguments supporting the multilateral nature of solar geoengineering. Similarly, Sovacool et al. (2023) embrace this logic of militarization and agree on saying that solar geoengineering may become a cause of new conflicts trough forms of "weaponization and hostile deployment, insecurity and asymmetrical protection, miscalculation, and arms races along with counter-geoengineering" (p. 10).

### 4.2.2 Deployment scenarios: big powers, small states, or non-state actors?

Solar geoengineering technologies carry serious geopolitical concerns, but the technology is not at everyone's disposal. So, who would be the actor pursuing such a unilateral alteration of the climate system? The matrix below provided by Joshua Horton, one of the experts invited at the RFF Conference, is useful in answering this question as it gathers the most common attributes of solar geoengineering deployment, and it makes scenario analysis more straightforward. Of course, this table does not aim at being exhaustive, and there could be more elements to add. However, it represents a good starting point to build different scenarios, some of which might be impossible, but others could be plausible and achievable.

[17] Elizabeth Chalecki, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures,* 2023).

According to the matrix, deployment of solar geoengineering technologies changes along five variables: actors, objectives, scope, motive and design[18]. Therefore, any deployment could be pursued by different actors (e.g., big powers, small power, non-state actors), have different types of objectives (e.g., peak shave emissions, slow or stop the rate of global warming), aim at a particular scope (e.g., target the globe, target a specific region), be motivated by various reasons (e.g., geopolitical, prestige, shock), and designed in different combinations (e.g., speed, frequency and latitudes of deployment)[19]. The panelist believes that an optimal, feasible deployment scenario is a condition where the design of deployment matches with the objective.

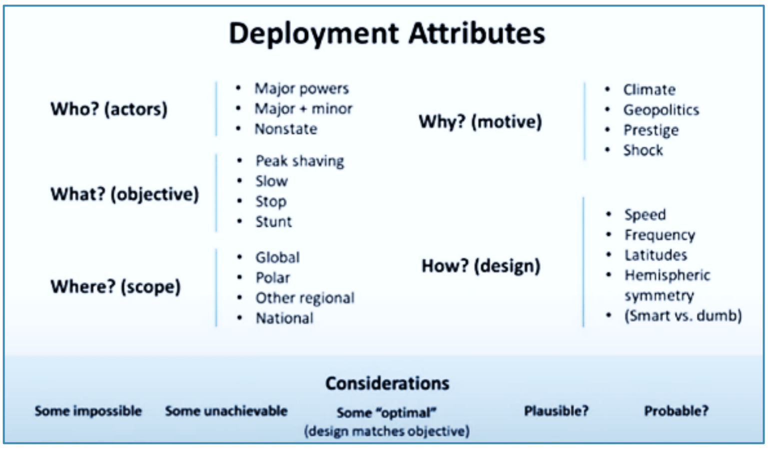



*Figure 5: Deployments attributes, RFF Conference panel: plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023).

The next paragraphs present an analysis of different scenarios according to the actors pursuing the deployment: non-state actors, small states, big powers, which are described in this section following Rabitz (2016) definition of these actor categories. First, when we talk about non-state actors involved in the solar geoengineering debate, we refer to: "businessmen, techno-entrepreneurs, inventors, scientists, but also interest groups from the fossil fuel industry which have vested interests in technologies which allow them to avert costly regulations and losses from the reduced consumption of fossil fuels" (Rabitz, 2016, p. 101). Second, the term small states indicate mainly Small Island Developing States (SIDS), who might have interests in solar geoengineering technologies to help them adapt to the exposure to sea-level rise. Finally, big powers are meant for those countries who "have easier access to relevant

[18] Joshua Horton, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)
[19] Joshua Horton, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023).

technologies as well as the ability to withstand diplomatic, economic, and possibly military pressure in reaction to a unilateral scheme" (Rabitz, 2016, p. 101).

As far as non-state actors are concerned, the experts have contrasting opinions on the role of the private sector. On the one hand, some believe that for example the space industry or the aircraft engine manufacturing industry has no role in developing and employing solar geoengineering technologies as it would still need the support from a sovereign state[20]. On the other hand, other experts acknowledge the possibility for the private sector to participate in solar geoengineering, which according to them would be an extremely dangerous scenario. Indeed, because the private industry is not subjected to the restraint of international law[21], and with their access to technological and economic resources, they would be able to do whatever brings them more profit. In this regard, J. Reynolds & Wagner (2020) studied the implications of a highly decentralized solar geoengineering deployment and described such a scenario as "technically possible, economically feasible and potentially politically disruptive" (p. 929). Similarly, the UNESCO (2023) report highlights how the rather cheap costs of solar geoengineering technologies could attract companies and non-state actors towards investing in solar geoengineering. Another interesting scenario presented during the panel was the possibility for non-state actors to collaborate in partnership with a sovereign country[22]. In such a setting, non-state actors would be able to pursue their economic interest, offering countries a convenient scapegoat should the circumstances turn unfavorable or a trial experiment to evaluate the real potential of solar geoengineering. Finally, it is also worth pointing out that non-state actors have increasingly become important figures in the international arena and in the climate change regime. Through their resources and positions they might be able to shape debates and perceptions, thus exerting pressure and leverage on governments to make sure the discussions and legislation on solar geoengineering go towards their preferred direction (J. Reynolds & Wagner, 2020). Therefore, solar geoengineering deployment scenarios involving the role of non-state actors, even if unlikely, still need to be considered to present a comprehensive analysis of solar geoengineering deployment. Given the worrisome absence of states views in the debate on solar geoengineering technologies, this may lead to an ungoverned field in which non-state actors, worried about the insufficient advancement in solar

[20] Daniele Visioni, RFF Conference Panel: "*Biophysical impacts: climatic & non-climatic risks and benefits*" (*Solar Geoengineering Futures*, 2023) / Douglas MacMartin, RFF Conference panel: "Solar geoengineering's place within the broader climate strategy portfolio".
[21] Elizabeth Chalecki, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)
[22] Ibid.

geoengineering, might overtake the matter into their own control (J. Reynolds & Wagner, 2020).

The scenarios on solar geoengineering deployment by a small state are as debated as those for non-state actors. Indeed, Halstead (2018) and Horton (2011) believe that a scenario in which a small state unilaterally deploys solar geoengineering is highly unlikely due to the incapability of sustaining the costs of potential repercussions, like sanctions or the use of force, following the uncoordinated intervention. However, as for the case of non-state actors, small state scenarios should not be so easily dismissed and still require our attention. For example, in front of a climate emergency a small state, or a coalition of small, vulnerable states, could be forced to deploy solar geoengineering to ensure its survivability and protect its national interests. Mariia Belaia at the RFF Conference highlighted that due to developing countries' low adaptive capacity the prospect of pursuing solar geoengineering could sounds to them quite appealing[23]. This idea of survival would be the first motive to push small states, like Pacific SIDS or Arctic states, to take the matter in their hand and unilaterally save themselves through solar geoengineering technologies (Rabitz, 2016). In this regard, solar geoengineering "could be the panacea they are searching for in their quest to stabilize the climate or a potential anthropogenic catastrophe in the making" (Lefale & Anderson, 2014, p. 1). "The domestic political demands that some leaders will be facing in these countries to do something about [climate change] will be incredibly high, and they'll be looking for options; and I don't think they have to do it well or do it right to do it in a way that creates real challenges and risks."[24]

To further understand a potential involvement from small states into solar geoengineering unilateral deployment, the theoretical lens of just war theory provides interesting perspectives on the matter. Chalecki & Ferrari (2018) believe that the criteria linked with just war theory are useful in evaluating the ethical and security characteristics of solar geoengineering deployment. On the one hand, a nation could be drawn into deploying solar geoengineering as an offence, an act of war, which would represent a violation of sovereignty; on the other hand, the increasingly strong climate impacts might lead a country into pursuing solar geoengineering as an act of defense (Chalecki & Ferrari, 2018). The second scenario is particularly relevant for the case of small state solar geoengineering deployment, as "given the existential threat climate change imposes on low-lying nations, one can conclude that these states possess a just

[23] Mariia Belaia, RFF Conference panel: *"Solar geoengineering's place within the broader climate strategy portfolio"* (*Solar Geoengineering Futures*, 2023)
[24] Erin Sikorsky, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar Geoengineering Futures*, 2023)

cause for the unilateral deployment of solar geoengineering" (Fruh & Hedahl, 2019, p. 390). Therefore, if one considers climate change as an act of war, small states which are most vulnerable to its impact would have the right to deploy solar geoengineering and this defense actions would satisfy all the criteria of the just war theory: right authority, right intentions, reasonable hope of success, wide proportionality, and last resort (Fruh & Hedahl, 2019). Thus, from a just war theory perspective, small states and SIDS would be justified to deploy solar geoengineering in self-defense against the climate emergency, on the contrary "the unilateral use of solar geoengineering by powerful nations who are most responsible for climate change but least vulnerable to its most adverse consequences, for instance, would be rightly condemned as unjust" (Fruh & Hedahl, 2019, p. 395).

Nevertheless, despite their potential interests in unilateral deployment, small states and non-state actors have some insurmountable obstacles to overcome that make scenarios in which they unilaterally deploy almost impossible. Indeed, according to Rabitz (2016) small state and non-state actors are constrained by technological, geographical and financial limits which they cannot surpass in the near future. For example, they would need the airspace access to allow aircrafts to operate undisturbed, they should have the financial resources to sustain the deployment, and, above all, they would necessitate the technological expertise to build SAI technologies or the permit to buy such high-altitude planes, which are usually regulated by arms export legislation (*Solar Geoengineering Futures*, 2023). A useful lens through which is possible to understand these intricate challenges to small states or non-state actors' deployment is the use of the concept of *performative deployment*, introduced by Jessica Seddon at the RFF Conference. A performative deployment is a condition in which the solar geoengineering intervention can be sustained by the deploying actor while producing the intended effects. Therefore, taken this into account, a potential solar geoengineering deployment scenario needs to satisfy the performative criteria to be considered achievable. Thus, only through a coalition or the support of a big power non-state actors and small states would be able to deploy solar geoengineering. Consequently, this leaves only great powers the capability to deploy unilaterally both in the short and long term.

Powerful countries are those who have the power to unilaterally sustain a solar geoengineering deployment and who are not restricted by financial or technological limitations as small states or non-state actors. During the RFF Conference, the panelist listed the US, the UK, France, Germany, Japan, Russia and China as the most likely countries to pursue unilateral deployment[25]. Therefore, any unilateral deployment scenario would see one of these countries intervene in the climate system, as they have the resources to build the aircraft and the power to maintain the deployment over time. In this regard, Surprise (2020) refers to the concept of *planetary sovereignty* to describe the power to define what is an emergency, to initiate solar geoengineering and ensure the deployment legitimacy. Whoever holds this power would reluctantly renounce it, unless through a partnership in which such country would be the dominant player able to grant or deny access to the technology (Surprise, 2020a).

To recapitulate, figure 6 below adapted from Rabitz (2016), summarizes visually what has been said in this section on unilateral deployment. Great powers represent the actor who would be able to individually deploy both in the short and long term, whereas deployment by non-state actors or small states is only possible in the long term and in specific conditions: for small states the climate intervention requires them to be in a state of climate emergency; and for non-state actors the involvement in solar geoengineering deployment would depend on the R&D costs and on national or international regulations (Rabitz, 2016). Therefore, there are numerous possible deployment scenarios, and it is possible as well that solar geoengineering technologies will be implemented through a combination of different actors. For example, Reynolds & Wagner (2020) highlight how "there could, however, be significantly smaller-scale technologies available, such as, for example, unmanned high-altitude balloons, for which technical and financial barriers to entry have greatly decreased in recent years" (J. Reynolds & Wagner, 2020, p. 922). Thus, increasing the possibility for non-state actors and small states to unilaterally deploy solar geoengineering.

| | SAI, short term | SAI, long term |
|---|---|---|
| Great powers | Possible in response to a climatic emergency | Possible in response to a climatic emergency |
| Small states | Not possible, lack of delivery systems/ geographical access; cost constraints | Possible in response to a climatic emergency if delivery systems are available and no-fly zones cannot be enforced |
| Non-state actors | Not possible, lack of delivery systems/ geographical access; cost constraints | Possible for demonstrating the technology's commercial value/safety if delivery systems are available and national authorities do not interfere |

*Figure 6: deployment scenarios adapted from Rabitz (2016).*

[25] Douglas MacMartin, RFF Conference panel: "Solar geoengineering's place within the broader climate strategy portfolio" (*Solar Geoengineering Futures*, 2023)

### 4.2.3 Countering solar geoengineering

So far, we have been discussing the possible ways in which solar geoengineering technologies could be deployed. However, to really understand the potential of unilateral climate intervention it is also important to focus on the diverse ways in which this can be prevented. Indeed, countries have at their disposal several options that have the potential to be a powerful tool to restrain unilateral intervention (e.g., injection of fluorocarbon gases to offset solar geoengineering cooling effect, use of black carbon to neutralize the albedo enhancement). Thus, counter-geoengineering can be considered a sort of security policy against unilateral deployment (*Reflecting Sunlight*, 2021) able to deter any uncoordinated action. In this regard, some experts are a bit hesitant in placing thrust into counter-geoengineering measures. For example, Michaelowa (2021) believes that such measures would not be implemented due to their negative side effects; on the contrary, Parker et al. (2018) consider these tools an effective practice in deterring unilateral solar geoengineering, a sort of veto power and response mechanism which represent a more proportionate reaction to unilateral deployment than that of the use of military force.

In academia Parker et al. (2018) are those who analyzed counter-geoengineering more extensively and in this section their view is presented. Counter-geoengineering refers to the "technical means to negate the change in radiative forcing caused by solar geoengineering deployment" (Parker et al., 2018, p. 1058), and can be divided into two different forms according to the purpose of the counter-geoengineering tool. On the one hand, there are countervailing measures, which consist of emitting warming agents, like GHGs. On the other hand, there are neutralizing measures, which would aim to neutralize the aerosol injected. Parker et al. (2018) purposely differentiates counter-geoengineering from actions that would for example target the infrastructure elements of solar geoengineering technologies (e.g., shooting down aircrafts), because these might be understood as a direct attack to the deploying state and lead to military action. But what would make counter-geoengineering an effective and credible deterrence mechanism? In this regard, the authors answer this question and define several elements. First, the measure must be economically feasible to deploy; second, the side effects produced should be low and avoid worsening the already critical situation of climate change; third, countervailing the intervention should employ chemicals with a similar lifetime to the technique it aims to counter; fourth and final, the possession of counter-geoengineering option should be knowledgeable to the international community. Taking all of this together, counter-geoengineering mechanisms have a real potential to prevent unilateral solar geoengineering deployment and in Parker et al.'s (2018) view they could also incentivize cooperation and multilateralism: "if a country wanted to conduct geoengineering, it would be forced to negotiate with states capable of counter-geoengineering over whether and how deployment was undertaken" (Parker et al., 2018, p. 1063).

Additional to counter-geoengineering techniques, there are also other more conventional ways to block unilateral deployment. For example, by applying diplomatic pressure or through the application of sanctions to deploying countries. However, the research on these options is still lacking or not sufficient, and because the climate regime does not have a sanction mechanism that can keep countries on check and prevent unilateral deployment, it is unlikely that these conventional methods would result to be efficient, (Michaelowa, 2021). In particular, Michaelowa (2021) believes that for large populist or autocratic countries sanctions would not be an efficient countermeasure against unilateral deployment, and only a large coalition of military powerful countries would be able to implement effective sanctions. Thus, the prospect of the use of counter-geoengineering could overcome this shortcoming of the international order, and in my view, it would balance the level playing field between different actors (e.g., presenting small states an insurance policy against the unilateral deployment of a powerful nation and vice versa). Despite having these characteristics, counter-geoengineering comes with certain risks, especially it could produce adverse consequences to the environment, it could worsen the already tense international order, and finally it would present a confirmation of the inability of the international system to regulate solar geoengineering in a constructive way (Parker et al., 2018).

Finally, another relevant limitation to unilateral deployment worth mentioning is the fact that solar geoengineering technologies, like SAI, are not there yet. The aircraft capability to inject aerosol 25 kilometer high into the stratosphere still needs to be designed and engineered (space aircrafts would not be suitable for SAI deployment because the uncertainties and controllability of the technology incrementally increases at those altitudes[26]). Therefore, currently no country would be able to unilaterally deploy. On the contrary, in the event of such aircraft being produced, only the six countries mentioned above (USA, China, Russia, France, Japan, UK) would be able to sustain a SAI intervention economically and technologically. And even if they could, they would still need an international consensus to avoid military escalation.

[26] Daniele Visioni, RFF Conference Panel: "*Biophysical impacts: climatic & non-climatic risks and benefits*" (*Solar Geoengineering Futures*, 2023).

## 4.3 PROCEDURAL JUSTICE

Solar geoengineering represents a newly, uncharted territory of climate governance; this means that it is not a fully developed and structured institution with clear regulatory frameworks and boundaries, and it still lacks formal norms and principles that can ensure this technology is researched, developed and maybe later deployed in a just manner. Therefore, considerations on justice are fundamental, and this section endeavor is to bring together the current understanding on procedural justice in the solar geoengineering debate.

As introduced in the conceptual framework, procedural justice refers to the procedures of the decision-making process and it entails different criteria and standard that, if followed correctly, they provide clarity to decision makers and ensure that the outcome of a decision is fair, participatory and broadly accepted by the public. Scientific attention on justice or ethical questions of solar geoengineering technologies is consistent, however mostly focused on distributive and intergenerational forms of justice[27]. Indeed, there is a worrisome lack of attention on the procedural justness of these technologies, and often in scientific papers or authoritative assessments there is not a clear, precise reference on how to secure procedural justice in the processes concerning solar geoengineering. For example, some reports focus themselves only on a more general focus, for example by applying “environmental justice” as an overarching concept in which clustering together different dimensions of justice (CSIGG, 2023; OSTP, 2023; *Reflecting Sunlight*, 2021; UNEP, 2023; UNESCO, 2023). Nevertheless, this approach might miss some important aspects or elements and consequently build a narrow understanding of the possible justice implications of solar geoengineering. Furthermore, recently the Human Rights Council Advisory Committee pronounced itself on the matter of climate protection technologies and the impact these have on human rights. Particularly, they highlight how the enjoyment of the right to a clean, healthy and sustainable environment might be jeopardized by the testing and deployment of such innovations. According to the Council, these technologies might “further violate the procedural dimension of this right, namely: access to information, participation in decision-making and access to justice and effective remedies” (OHCHR, 2023, p. 13).

Therefore, procedural justice is an extremely broad concept, and its implication might touch upon the way research is structured, how the public is engaged and included in the design

[27] Marion Hourdequin, RFF Conference panel: *“Capacity building for competent, just and inclusive decision making”* (*Solar Geoengineering Futures*, 2023)

of solar geoengineering technologies, and how decisions are taken considering power dynamics and structural inequalities. It is an all-encompassing form of justice that is fundamental to be established at these preliminary stages of the solar geoengineering discussions to avoid future injustices. Overall, out of the nine authoritative assessments scrutinized, only three (Felgenhauer et al., 2022; Florin et al., 2020; *Reflecting Sunlight*, 2021) mention and analyze procedural justice as an important concern for solar geoengineering decision-making processes. As far as the RFF Conference is concerned, ethical and justice concerns were considered throughout most of the panels, but especially in the discussion on *"Capacity building for competent, just and inclusive decision-making"*. Finally, in the academic field thirteen different scientific papers (listed below) were identified as dealing with procedural justice and its attributes. The following paragraphs unpack procedural justice and try to understand what it means to ensure a procedurally just decision-making process in the field of solar geoengineering technologies.

| **Procedural justice** | | |
|---|---|---|
| Author | Date | Title |
| Svoboda et al. | 2011 | "Sulfate aerosol geoengineering: the question of justice" |
| Breena Holland | 2017 | "Procedural justice in local climate adaptation: political capabilities and transformation change" |
| Marion Hourdequin | 2018 | "Climate change, climate engineering and the 'Global Poor': what does justice require" |
| Marion Hourdequin | 2018 | "Geoengineering justice: the role of recognition" |
| Clare Heyward | 2018 | "Normative issues of geoengineering technologies" |
| Duncan P. McLaren | 2018 | "Whose climate and whose ethics? Conceptions of justice in solar geoengineering modelling" |
| Brandstedt & Brülde | 2019 | "Towards a theory of pure procedural climate justice" |
| Daniel, Edward & Callies | 2019 | "Institutional legitimacy and geoengineering governance" |
| Augustine Pamplany | 2020 | "The ethical desirability of geoengineering: challenges to justice" |
| Sovacool, Baum & Low | 2022 | "Climate protection or privilege? A whole systems justice milieu of twenty negative emissions and solar geoengineering technologies" |
| Mettiäinen et al. | 2022 | "Bog here, marshland there: tensions in coproducing scientific knowledge on solar geoengineering in the Arctic" |
| Marco Grasso | 2022 | "Legitimacy and procedural justice: how might stratospheric aerosol injection function in the public interest?" |
| De Ridder et al. | 2023 | "Procedural climate justice: conceptualizing a polycentric solution to a global problem" |

### 4.3.1 Inclusive and fair solar geoengineering decision-making

The core characteristic of procedural justice is participation, which is the first element that needs to be guaranteed for the establishment of procedurally just decision-making processes. However, contrary to what one might think, meaningful participation is hard to achieve and requires the overcoming of certain barriers. In this regard the National Academies of Science report (2021) provides a crucial attribution to participation and specifies that participation needs to be *fair*. This is particularly important because by ensuring fair participatory processes we acknowledge the fact that actors are not on the same level, that their opportunities to participate vary according to several factors (e.g., knowledge, information, positionality, economic factors, culture etc.), and that decisions are usually not taken on a level playing field. This means, for example, that fair participation cannot be achieved with the wide and persistent knowledge and research gap between the Global North and the Global South[28]. Indeed, so far most of the solar geoengineering research and discussions have been centered in the developed areas of the world, while the role of developing countries in the solar geoengineering debate has remained marginal and mostly not accounted for.

According to Stephens & Surprise (2020), the current production of solar geoengineering research is perpetrating the same unequal power and knowledge dynamics that divide the Global North from the Global South. In these settings, researchers push for solar geoengineering without addressing colonial legacies or taking into consideration the burdens that developing countries or vulnerable communities might face from solar geoengineering deployment. McLaren & Corry (2021) highlight additional shortcomings of solar geoengineering research, and they advocate for a structured governance of the field. Particularly, the authors stress the tendency of academics to overlook the importance of "cultural, economic, political, and international contexts" contributing to the replication of dominant perspectives and power dynamics. Elitist, north-centric research centers have considerably decreased developing countries' chances to actively engage and participate in the decisions on solar geoengineering technologies, and to raise their valuable concerns[29]. Therefore, before starting the discussions on participation it is necessary to bridge the gap between the Global North and the Global South and level their capacities to ensure their participation happens in a just, inclusive and meaningful way. It is widely recognized that the most vulnerable and exposed populations to the adverse impacts of climate change come from the rural, poor and Indigenous communities in developing countries; and due to their lower capacity to build resilience, they should have a privileged position in the decision-making process on solar geoengineering technologies, and their voice and concerns should be listened first. Thus, according to Callies (2018), "given the potentially beneficial and potentially

[28] Hassan Sipra, RFF Conference panel: *"Capacity building for competent, just and inclusive decision making"* (*Solar Geoengineering Futures,* 2023).
[29] Hassan Sipra, RFF Conference panel: *"Capacity building for competent, just and inclusive decision making"* (*Solar Geoengineering Futures,* 2023).

catastrophic effects geoengineering could have on, say, those residing within small island states, any process that failed to include these people and allow their voices to be heard on reasonable terms of participation would be procedurally unjust (regardless of the substantive outcome)" (p. 335). So, how can we make sure the participation is fair?

### 4.3.2 Navigating dynamics of participatory parity, recognition and paternalism

The concept of *participatory parity* and *recognition* can help clarify what does it means to provide fair participation in solar geoengineering decision-making. By definition, the former concept describes a situation where "people have the opportunity to engage as peers in decisions that affect them" (Hourdequin, 2019, p. 469); in practical terms this ensures that the actors who participate in the decision-making processes have equal status and standing. The latter term, recognition, instead requires "basic respect and robust engagement with and fair consideration of diverse values, cultures, perspectives and worldviews" (Hourdequin, 2019, p. 450). According to Hourdequin's perspective the combination of participatory parity and recognition should be present in any development of geoengineering governance and research. On the one hand, participatory parity makes sure that the actors participate on the same level and with equal power to contribute and influence the decision-making process, and recognition on the other hand, acknowledges and respect their diversity and tries to integrate this variety of perspectives in the process.

Combining participatory parity and recognition in the procedural justice of solar geoengineering is not only about enhancing participation, but also about understanding and tackling power dynamics that might further marginalize already disregarded perspectives[30]. Indeed, by linking these two fundamental concepts it is possible to avoid the perpetuation of power dynamics that disregard marginalized voices and take decisions based on unquestioned assumptions, and it also prevents the misrecognition of the context of solar geoengineering[31]. In technologically complex and unregulated domains, such as solar geoengineering, a common occurrence involves crucial decisions being made by expert elites on behalf of the public, often without their full participation and driven by a presumption of superior knowledge, and the belief that actions are undertaken for the public's benefit. This is the case for example of climate models. Indeed, nowadays most of the decision regarding the climate are taken based on future

[30] Marion Hourdequin, RFF Conference panel: *"Capacity building for competent, just and inclusive decision making"* (*Solar Geoengineering Futures*, 2023).
[31] Ibid.

projections of global warming produced by sophisticated scientific models (D. P. McLaren, 2018). With the introduction of solar geoengineering technologies as a policy option for climate intervention, scientists have started to use model outputs to develop their arguments around these technologies. However, as McLaren (2018) highlights, these climate models pose serious problems of legitimacy as they are often built without consultation of the public and based on unquestioned presumptions from the dominant social imaginary.

Procedural justice, therefore, aims at avoiding such forms of *paternalism* in which decisions are taken "in the assumed interest of a person and without or against that person's informed consent" (Hourdequin, 2018, p. 276). This is particularly important for the case of solar geoengineering. A lot of arguments in favor of pursuing solar geoengineering develop the idea that these technologies would benefit especially the most vulnerable (see: Horton & Keith, 2016 and Flegal & Gupta 2018), however such claims are often made without the opinion of the directly concerned actors and are not necessarily evidence-based (Hourdequin, 2018). Thus, an additional concern is that paternalism may inadvertently foster *parochialism,* which is exactly a situation where the decisions are based upon assumptions. Why is paternalism and parochialism so damaging for procedural justice? In Hourdequin (2018) perspective paternalistic arguments on solar geoengineering are superficial as they assume that one's view is universally shared. This closed mindset ends up disregarding the self-determination of vulnerable populations, leading to a limited picture of what are the different opinions and perspectives on solar geoengineering and as well to new forms of expertise imperialism[32]. In practical terms, if such lack of reflexivity and critical thinking keeps influencing the decision-making process, it might happen that solar geoengineering would not respond to the needs and livelihoods of the populations to which the climate intervention was initially intended for. Furthermore, linking paternalism and parochialism to the shortcomings of climate models we further understand how the combination of a lack of participation, unquestioned assumptions and power dynamics can prevent the achievement of procedural justice. In this regard, it is important to reference to McLaren (2018) where the author states:

> "This [climate modelling approaches] represents a hierarchical model of control that is at worst a form of domination and at best, elitist paternalism. It treats those affected by climate change as powerless victims; not as potentially capable actors able to participate in determining the conditions of their lives – including participating in climate politics. This territory is implicitly

[32] Expertise Imperialism refers to a situation where expertise and the epistemic community exercise control through knowledge and status asymmetries, thus undermining recognition and participatory parity (Hourdequin, 2018). In Hourdequin's view this can be avoided by decentering research and decision-making.

> reserved for the scientific and political elites – notably in the countries which dominate climate geoengineering research: the US, UK, Germany and to a lesser degree, China. Moreover, if solar geoengineering merely masks the threat of climate injustice to future generations, rather than structurally or institutionally removing it in the way mitigation and adaptation do [92], then there is an equivalent intergenerational injustice involved. Put another way, mitigation and adaptation would appear inherently more supportive of future people's freedoms and capabilities because they reduce vulnerability to domination, especially if the underlying interventions, in energy systems for example, are undertaken with attention to fair distribution, recognition and procedure" (D. P. McLaren, 2018, p. 217).

The field of solar geoengineering without the proper countermeasures might reproduce forms of domination, unequal power dynamic and exclude marginalized voices as the ones of countries from the Global South. Following procedural justice in this field, therefore, can ensure fair participation, participatory parity and recognition, while avoiding paternalistic and parochialistic tendencies of solar geoengineering research and decision-making.

### 4.3.3 Exploring the all-affected principle, consent and elements of procedural justice

In the opening paragraphs of this section, it was highlighted how procedural justice is an all-encompassing concept, but even though participation represents a first step in ensuring justice in the field of solar geoengineering, a solid form of procedural justice requires further elements to consider. Among these a core procedural justice criterion is the all-affected principle, according to which all the affected parties by a certain decision or technology development should be included and heard. This concept is tightly linked with the above analyzed issues of recognition and participatory parity, as it would enable fairness, equality and equal standing when decisions are taken. For example, according to Sovacool et al. (2022) this important procedural characteristic is not observed in the case of SAI unilateral deployment, as it does not include all-affected actors in the decision-making and there is no mechanism to appeal in case of intervention. So, the all-affected principle is particularly relevant for solar geoengineering technologies because future decision-making "must pay attention to how deeply and fundamentally people's lives are affected" (Heyward, 2019, p. 651). However, this concept is not exempt from criticism and some experts recognize its scope as being too broad and unclear (de Ridder et al., 2023). For instance, defining who are these actors and how they are being affected might be complicated and it could again respond to power dynamics. Secondly, reaching deliberative processes in which everyone participates might be hard to achieve, and some underrepresented groups might not be included (for example is hard to represent youth, future generations or faith groups in the field of solar geoengineering, as in any other field)[33]. Despite this difficulty in defining the all-effected principle, it still represents a good exercise to ensure procedural justice and, as Julie Andrews at the RFF Conference suggested, when in doubt is useful to first identify all the relevant categories (local, regional, national, international), engage with them and then step back, see who is left behind and include also those overlooked categories and involve them into the conversations (*Solar Geoengineering Futures*, 2023).

Another relevant element to guarantee procedural justice in the field of solar geoengineering is consent. It represents a universal norm in research ethics, which ensures that a subject participating in a research project is adequately informed of the risks and that the consent is obtained after providing sufficient information (Pamplany, 2020). Thus, given the global scale of solar geoengineering it should be considered a "non-negotiable requirement of just procedure" (Pamplany, 2020, p. 9). Indeed, the main characteristic of solar geoengineering is that its impacts cannot be restricted to specific areas of the globe, on the contrary, the positive or negative effects of a potential deployment will likely be perceived by everyone and everywhere. Therefore, securing informed consent of the parties affected is crucial to establish procedurally just processes in this field. However, according to Pamplany (2020), and similarly with the all-affected principle, consent comes with challenges in identifying the victims of the research and deployment and in ensuring that the consent would lead to inclusive forms of representation. Additionally, due to the persistent knowledge and research gap between the developed and developing countries, it is likely that research and deployment would proceed without the consent of these underrepresented perspectives (Sovacool et al., 2022). These concerns are legitimate, especially when considering the completely excluded perspective of Indigenous communities in the solar geoengineering debate. On this unbalanced dynamics, Grasso (2022) also states that procedural justice would prevent solar geoengineering being manipulated by elites' interests, who usually disregard the value of consent, and it would also make sure that any solar geoengineering research or deployment is aimed at the public interest. Additionally, also in this case a unilateral deployment would not be considered procedurally just as probably the intervention would be pursued without the consent of some countries or the public (Svoboda et al., 2011). Therefore, securing the informed consent of the affected

[33] Marion Hourdequin, RFF Conference panel: *"Capacity building for competent, just and inclusive decision making"* (*Solar Geoengineering Futures*, 2023).

stakeholders would automatically establish procedures that are just, avoid paternalistic assumptions and impede reckless deployment.

Finally, further important norms of procedural justice are possible to identify to make sure decisions are being taken in a procedural just way. For example, norms like self-determination, transparency and voice can help reach just outcomes in the field of solar geoengineering. Firstly, self-determination is linked with issue of sovereignty and recognition, and it basically avoids any form of domination that would impose the interests of the Global North to the South (Ridder et al., 2023). Secondly, transparency is particularly important to ensure the decision-making processes are legitimate and based on disclosed information (Brandstedt & Brülde, 2019; Heyward, 2019). Indeed, a transparent process is procedurally just because all the steps of research and decision-making, from the data collection and analysis to the final product, are publicly and freely available for consultation (de Ridder et al., 2023). Thirdly, voice could be considered a basic requirement for procedural justice as it entails the right and chance, especially for vulnerable and underrepresented actors and more in general for all the affected, to voice concerns, opinions and share knowledge, and thus, shape the decision-making process (Callies, 2018; de Ridder et al., 2023; Holland, 2017; Hourdequin, 2018).

#### 4.3.4 Procedural justice and indigeneity

As previously mentioned, solar geoengineering technologies can either replicate power dynamics or exacerbate existing inequalities. Consequently, discussions regarding procedural justice in solar geoengineering must include the evaluation of aspects of indigeneity and Indigenous perspectives. These elements are often overlooked in the climate governance and solar geoengineering domains, posing significant challenges for data collection. For instance, authoritative assessments often neglect the role of Indigenous people in the solar geoengineering debate. Only three reports address the issue: Florin et al. (2020) acknowledges the insufficient representation of Indigenous communities in the discussions on solar geoengineering; whereas both UNEP (2023) report and the National Academies of Science (2021) emphasize the significance of obtaining consent from Indigenous peoples and communities, given their frequent exclusion from decision-making processes and limited access to knowledge about solar geoengineering. Similarly, the RFF Conference superficially touches on the topic of indigeneity in solar geoengineering developments. This absence raises concerns from a procedural justice point of view, as it risks compromising fair participation, recognition and consent of all the affected parties. Therefore, it is necessary to enhance the capacity of Indigenous people to engage meaningfully in the solar geoengineering debate. The only comprehensive assessments completely dedicated to the nexus between indigeneity and solar geoengineering is published by the Convention on Biological Diversity (2012), in which the views and experiences of Indigenous and local communities are presented.

The general lack of consent from Indigenous people when it comes to solar geoengineering is a concerning issue in the field of climate governance. Indeed, often Indigenous sovereignty and consent is ignored, not respected and completely disregarded (Whyte, 2012a). The main scholar who extensively analyzed the link between solar geoengineering and indigeneity is K. P. Whyte, and here his work is synthesized. Firstly, Whyte strongly critiques the argument advanced by solar geoengineering supporters who believe that climate intervention would primarily benefit vulnerable communities, and that if compared to the impacts of climate change it would represent the lesser of two evils (Whyte, 2012a). In Whyte's view, and from a procedural justice standpoint, such argument is particularly detrimental as it can be viewed as a mechanism for silencing Indigenous people and their dissent (Whyte, 2012b). Additionally, in analyzing indigeneity in solar geoengineering discourses, Whyte critically observes how hard it is for Indigenous people to voice their perspectives in this highly technocratic, north-centric field of solar geoengineering technologies (Whyte, 2018). Particularly, he links this difficulty to historical inequalities and power dynamics, and says how "imperialism and settler colonialism have rendered a situation in which many Indigenous peoples do not have local leverage to consent or dissent to any projects that might affect them" (Whyte, 2018, pp. 301–302). Furthermore, Whyte states that "for many Indigenous peoples, solar geoengineering represents a particular global path-dependence for responding to climate change that will simply sweep them up before they have had any chance to influence or meaningfully consent to various courses of action" (Whyte, 2012a, p. 175). So, it is striking the disadvantaged position that Indigenous people have in the solar geoengineering debate. The combination of historical inequalities with technological and scientific complexity of solar geoengineering and the concentration of research in wealthy countries largely reduce Indigenous capacities to engage with this topic and provide their consent or dissent, to the point where experts have described this new climate governance field as a new form of climate colonialism (Sovacool et al., 2022).

Furthermore, as for beliefs and worldviews, Indigenous peoples have different opinions towards solar geoengineering, and given their absence in the conversations their diversity is often overlooked (Mettiäinen et al., 2022). Indeed, in such holistic communities, based on traditional ways of life strongly connected to nature, solar geoengineering represents a contrasting approach to their way of dealing with environmental problems and climate change. For example, the Sámi people have underlined that "climate manipulation strongly contradicts our understanding and experience of how to respect and live in harmony with Mother Nature, and therefore, this technology is not something we see as a part of our chosen future" (Risse, 2023, p. 3). Such Indigenous skepticism was also pointed out during the RFF Conference where the panelist expressed how Global South countries or Indigenous communities are becoming more and more suspicious towards these technological advancements coming from the North[34]. Consequently, obtaining a form of consensus from Indigenous communities over solar geoengineering advancements will be challenging, as exemplified by the recent headline case on the Harvard University's solar geoengineering SCopEx project being blocked by the Sámi Council in 2021 (Risse, 2023). The Sámi Council's suspension was the result of a legitimate concern: the absence of consultation and consent within the affected communities, directly contradicting the principles prescribed in the UN Declaration on the Rights of Indigenous People (Oksanen, 2023). Representing Indigenous Arctic communities and being at the forefront for Indigenous recognition in environmental matters, the Council demanded the refusal of solar geoengineering as a climate policy option and the termination of experiments in the region and globally (Risse, 2023). This case serves as a crucial precedent for the future developments of solar geoengineering, and it confirms Indigenous communities' "normative power in conferring or denying legitimacy to geoengineering research" (Oksanen, 2023, p. 2). Furthermore, it highlights the need to include and engage with Indigenous opinions and communities in every stage of solar geoengineering research and decision-making, given their key role as stakeholders in the debate and in light of the potential impacts of solar geoengineering to their traditional livelihoods, values and beliefs (Oksanen, 2023). In particular, Arctic Indigenous communities require special attention and inclusion as the Arctic region is often considered to be an ideal regional deployment of solar geoengineering to halt sea-ice melting and preserve Indigenous traditional hunting areas[35]. However, the lack of engagement and participatory decision-making processes drastically diminish Arctic communities' opportunity to express their voice and be active agents in the development of climate policy options (Buck, 2018; Friedrich, 2023; Mettiäinen et al., 2022). Thus, this

[34] Hassan Sipra, RFF Conference panel: *"Capacity building for competent, just and inclusive decision making"* (*Solar Geoengineering Futures,* 2023).
[35] John Moore, RFF Conference Panel: "*Biophysical impacts: climatic & non-climatic risks and benefits*" (*Solar geoengineering Futures*, 2023).

highlight how crucial it is to ensure procedural justice in solar geoengineering developments and once again emphasizes the necessity to improve inclusion and participation of Indigenous people in the debate.

To conclude, the lack of careful attention to Indigenous people’s views and needs is a problematic shortcoming of the solar geoengineering debate and an intricate obstacle for procedural justice to overcome. Therefore, reaching procedurally just processes in this new field of climate governance would require engaging with Indigenous communities to bring at the table their diverse perspectives and concerns, as well as ensuring they have agency and control over their territory and futures to avoid any further marginalization. In the field of solar geoengineering establishing procedural justice also entails the integration of Indigenous people as equal partners in the development, design or deployment of the technology (Holland, 2017) and the incorporation of their local and traditional systems of knowledge (Heyward, 2019).

## 4.4 CONCLUDING REMARKS

This empirical chapter answers the first sub-research question of this thesis and provides an extensive analysis of the state-of-the-art and of the various perspectives and contestations in the three core concepts of the solar geoengineering debate. In this concluding section some final remarks are presented and summarized in *figure 7* below.

Firstly, the data collected on mitigation deterrence show how this phenomenon emerges according to three different scale: individual, social and political. So far considerable academic attention has been placed on evaluating the individual level. Particularly, as the studies on individual mitigation deterrence leads to reject the argument of reduced mitigation efforts following the prospect of solar geoengineering, the social and political scales are completely disregarded in academia. As a result, there is an imbalance between the empirical assessments of mitigation deterrence, which do not provide the full picture of how solar geoengineering technologies might affect mitigation or other climate policy options. Additionally, given the novelty of the field and low public awareness, the future presence of mitigation deterrence will most likely be determined by framings and worldviews. For example, describing solar geoengineering as a perfect substitute of mitigation considerably increases the chance of the technology becoming a mitigation deterrent, highlighting the problematic use of substitution logics. Finally, the hard-to-solve controversy over the concept of mitigation deterrence confirms the need for future research to shift focus from simply proving or disproving moral hazard to more detailed investigations of the technology (McLaren, 2016).

Secondly, the data validate unilateral deployment as a serious geopolitical concern, especially when considering scenarios involving powerful countries. However, by focusing only on the geopolitics of nation states we might miss some important considerations. Therefore, acknowledging and studying scenarios involving non-state actors or small states provides a clearer picture of the debate on unilateral deployment of solar geoengineering. In this regard, a satisfactory solution to understand which scenarios are more plausible than others is to think in terms of performative deployment. Overall, unilateral deployment of solar geoengineering should be avoided and prevented, especially at these early stages of technology research. Currently unilateral deployment is blocked by technical, economic and political limitations, which could be overcome in the future as such obstacles and uncertainties are solved with further research. Therefore, it is necessary to develop the necessary countermeasures, reduce the incentives to deploy and establish multilateral cooperative mechanisms.

Thirdly, despite being a minor area of the justice debate, procedural justice is particularly important in the field of solar geoengineering. Indeed, ensuring procedural justice at these early stages of solar geoengineering development is beneficial to enhance future justness of solar geoengineering technologies. Indeed, this justice dimension makes sure that the decision-making process is done in a participatory, inclusive and fair mode, in which different actors and perspectives are taken into account. By providing voice, agency, transparency and securing the consent of the affected parties, procedural justice has the potential to address existing inequalities and power dynamics that usually prevent underrepresented and marginalized actors to actively engage into the discussions, or shape future solar geoengineering developments. Finally, through participatory parity and recognition it is possible to avoid paternalistic assumptions which are still present in such technocratic fields and used to perpetrate dynamics of domination and exclusion. In this regard, procedural justice can help embrace and include the diversity of actors, for example by recognizing the fundamental role of Indigenous people both as affected actors and as knowledge holders.

Considering all of the above, mitigation deterrence, unilateral deployment and procedural justice each create specific challenges that make solar geoengineering a complex and multifaceted topic. Consequently, its governance design is equally difficult to shape. These fundamental principles necessitate targeted strategies to address their associated challenges. Specifically, confronting the challenges of preventing mitigation deterrence entails a focus on framing, social and political levels, and avoiding substitution logics. Similarly, tackling the issue of unilateral deployment requires implementing countermeasures and examining scenarios involving non-state actors and small states. Moreover, achieving procedural justice involves fostering inclusivity, encouraging participation, recognizing diverse perspectives, and addressing historical inequalities. Given these complex requirements, the question arises: how feasible is it to meet these demands and effectively govern such a contentious field? Is there a most-suited way to ensure procedural justice and avoid mitigation deterrence and unilateral deployment in solar geoengineering future developments? The next chapter, focusing on the second sub-research question, tries to answer some of these concerns by interpreting the governance implications and identifying the necessary forms and requirements of future solar geoengineering governance.

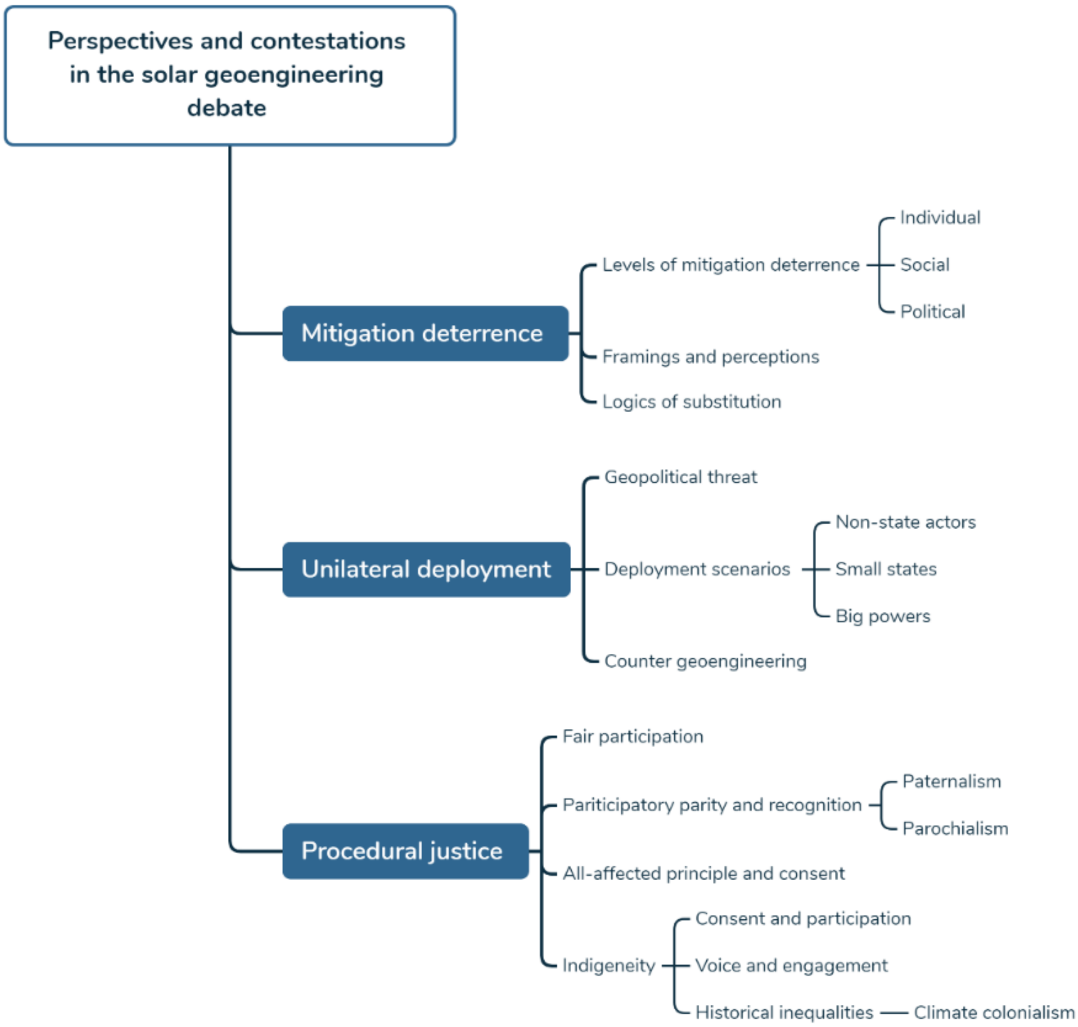



*Figure 7: Summary of empirical chapter 4 – Unpacking the solar geoengineering debate.*

# 5 SOLAR GEOENGINEERING IMPLICATIONS FOR GOVERNANCE

In Chapter 4 the three core concepts of this thesis are unpacked to structure the state-of-the-art in the solar geoengineering debate. From their analysis several uncertainties, diverging perspectives and challenges emerge. Therefore, this second empirical chapter builds on the previous inquiry and concentrates on the crucial role of governance in responding or preventing the implications arising from mitigation deterrence, unilateral deployment and procedural justice. Thus, Chapter 5 answers the second sub-research question of this research project: *"How can future governance of solar geoengineering navigate the implications associated with ensuring procedural justice, while preventing mitigation deterrence and unilateral deployment, and how feasible is it, also given the uncertainties and diverse perspectives surrounding these pivotal challenges?"* (SRQ2).

Answering this question is particularly relevant for the solar geoengineering debate because future governance structures will be essential in determining a suitable climate policy portfolio. Whether solar geoengineering technologies will be part of countries' response to the climate emergency or not, these planetary-level interventions will require governance mechanisms to ensure fairness and participation, while avoiding an uncoordinated deployment and the risk to reduce mitigation efforts. In this regard, the Climate Overshoot Commission's report published this year identifies six governance challenges of solar geoengineering: "1) reaching an international agreement whether to use solar geoengineering or not and deciding the scale of intervention; 2) the risk of reducing mitigation efforts; 3) establishing effective cooperation to prevent unilateral deployment; 4) building durable framework; 5) compensating countries adversely affected by solar geoengineering; 6) ensure meaningful participation in decision-making" (Reducing the Risks of Climate Overshoot, 2023). Particularly, among these obstacles, challenge number two, three and six relate closely with the three core concepts of this thesis, confirming the urgency of establishing solar geoengineering governance in this field.

This chapter starts with a preliminary and general consideration on solar geoengineering governance and which elements should be present to govern this new field. Subsequently, the following sections dive more deeply into the implications related to each concepts analyzed and the role of governance in addressing them.

## 5.1 SOLAR GEOENGINEERING GOVERNANCE'S MINIMUM REQUIREMENTS

From the data collected, three main themes of solar geoengineering governance emerge: *research governance*; *communication*; *cooperation and collaboration*. These fundamental elements of governance should be considered as the minimum requirements for an effective and inclusive form of governance that is able to avoid the risks linked with mitigation deterrence and unilateral deployment, while including and answering to people's needs. So, the presence and the combination between these elements should be ensured in the solar geoengineering debate and in the developments of future governance frameworks.

### 5.1.1 Research governance

The field of solar geoengineering, due to the absence of formal, explicit regulatory mechanisms, can be considered a sort of *terra nullius,* where much is still uncertain. This is particularly true for research in this field, where the epistemic community holds the power to determine the direction of solar geoengineering technologies development. Therefore, establishing clear norms and regulations for research is crucial for future solar geoengineering governance.

The authoritative assessments analyzed agree on saying that solar geoengineering governance should also advance governance principles for research. Indeed, for solar geoengineering, there are currently no procedures or guidelines that can ensure that the research process is done properly. And given the significant power that scientific research has in shaping and framing environmental futures, and consequently influencing the decision-making process, the governance of research should become a priority in the field of solar geoengineering (*Reflecting Sunlight,* 2021). Especially because solar geoengineering governance is considerably behind schedule in respect to its research (CSIGG, 2023), the attention should be placed on building governance right now, and this should be done simultaneously with research processes, as they both need to co-evolve and interact between each other (*Reflecting Sunlight*, 2021; UNEP, 2023). Research is not neutral and it can shape and develop futures, therefore, its design and regulation should be considered in an on-going process: the model of first developing the technology and then figuring out its governance should not be applied to solar geoengineering, as it poses pressing social issues that science alone is not able to address (*Reflecting Sunlight*, 2021). In particular, UNEP (2023) and Climate Overshoot Commission's (2023) authoritative assessment call for the establishment of governance regulations to avoid small or large-scale outdoor experiments of solar geoengineering, in this way “limiting the potential of a slippery slope towards large-scale deployment” (UNEP, 2023, p. 24). Additionally, the Climate Overshoot Commission believes that “governance of scientific activities should seek to strike a balance between the need to learn more about solar geoengineering and the need for precautionary management of physical risks” (Reducing the Risks of Climate Overshoot, 2023, p. 92), but it also recommends the application of a moratorium on the deployment of solar geoengineering and large-scale outdoor experiments.

On the efficacy of a moratorium the scholarship is rather divided. On the one hand, some believe that a moratorium would be useful to shift away the focus from deployment, help concentrate on building the governance structures needed, and set a precedent for some form of cooperation in the field (*Solar geoengineering Futures*, 2023). On the other hand, experts are more skeptic about the effectiveness of implementing a moratorium. For example, Morrow (2014) argues that the current uncertainties around solar geoengineering do not justify a moratorium, but rather a more precautious approach. Harding et al. (2023), in analyzing the costs of information on solar geoengineering, conclude that placing a moratorium on research and deployment would be extremely costly. Similarly, Parker (2014) critiques the arguments pushing for ‘governance before research’ as it would be counterproductive, hard to agree on and it might stigmatize or delay research before addressing the uncertainties of the technology. In line with this argument, the paper by Táíwò & Talati (2021) adds that “a ban at this stage of low information and low involvement of Global South researchers and policy makers—especially if done at the behest of Global North researchers and organizations—is premature and undemocratic”. Despite this controversy over the value of a moratorium, unregulated research on solar geoengineering can be dangerous and easily manipulated, therefore, it should be controlled with proper governance instruments. Correctly designed governance mechanisms have the potential to reduce, and if not contain, some of the concerns arising from mitigation deterrence or unilateral deployment, while securing principles of procedural justice (the how is described in the following section).

This leads to the question whether solar geoengineering research should be allowed to continue unregulated, or should it be restrained by strong governance rules and norms. A perfect formula does not exist, there are risks both with allowing and denying research (Jinnah et al., 2019), but finding a balance between scientific freedom and governance is possible and fundamental. On this matter, the RFF Conference attended in September 2023 presented both side of the debate. On the one hand, the panelists warned how regulating research based on the controversial idea of the topic is rather superficial:

> "There are a lot of politically controversial topics around human sexuality and reproduction, around politics, around gun control. If we really set up systems that says you're not allowed to do research if it is potentially controversial, there'd be some benefits because there is some research that is bad. But there would be some real limitation in our ability to do research on topics that are controversial, which is, I think, part of the function of the not centrally controlled system that we have in democracies for universities doing research."[36]

This argument is based on the idea that historically social change has always been brought up by processes that involved alien, controversial, or even incomprehensible ideas. And this is not something that is intrinsically bad. Solar geoengineering research could have the same faith, where first the idea of altering the climate system enters the discussions as the outcast but ends up saving lives of species and ecosystem and being normalized in climate governance[37]. Similar arguments against strict governance of solar geoengineering research can be found in the scholarship underestimating the risk of mitigation deterrence and unilateral deployment. Experts, for example, emphasize how the fear and concern over diminished efforts in mitigation and deployment might manifest a self-fulfilling prophecy[38]. In this scenario, reduced research in these areas could exacerbate the very risks that governance aims to prevent. Nevertheless, on the other hand, unrestrained solar geoengineering research comes with serious challenges such as technological lock-in, slippery slope towards deployment, mitigation deterrence or uncoordinated deployment (J. Reynolds, 2015; Burns et al., 2016; Jinnah et al., 2019; J. L. Reynolds, 2019; Harding et al., 2023). Therefore, the need for new and more deep knowledge on solar geoengineering should not obfuscate the real goal of climate governance and should not come at the people or environment's expenses. In this regard, Reynolds & Parson (2020) emphasize that research governance has three main goals: first enabling research; second controlling that the risks and harms are minimized; third, research governance legitimizes projects and ensures they are pursued responsibly. Thus, governance is greatly needed for research to continue. Through governance mechanisms for research, it would be possible to pursue academic freedom and increase our understanding on a climate tool that might become necessary in the future, while ensuring that this research is done in people's

[36] David Keith, RFF Conference panel: "*Important next steps for policy and research: a solar geoengineering research agenda for the next decade*" (*Solar geoengineering Futures*, 2023).
[37] Andy Parker, RFF Conference panel: "*Important next steps for policy and research: a solar geoengineering research agenda for the next decade*" (*Solar geoengineering Futures*, 2023).
[38] Erin Sikorsky, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar geoengineering Futures*, 2023)

interests, without threatening mitigation or becoming a geopolitical threat following an uncoordinated and ill-designed deployment.

Indeed, Jinnah et al. (2019) confirm that governance arrangements could make sure that "solar geoengineering remains subsidiary to mitigation and adaptation, that the climate intervention is responsive to societal needs and concerns, and that effective institutions and norms are established to govern decisions about potential deployment" (p. 4). The ways in which this can be done are multiple. First, there should be a close interaction between the social and natural sciences (Aldy et al., 2021). Given the worldwide implications and characteristics of solar geoengineering, an assessment of solar geoengineering that does not include social economic or cultural factors is inadequate for comprehending the potential benefits or drawbacks of climate engineering. Consequently, governance can ensure social sciences are combined within the research design and in the communication of results to policy-makers and the public (Burns et al., 2016; D. P. McLaren, 2018). For example, this can be done by establishing tailormade solar geoengineering Institutional Review Boards or Ethical Committees, which are commonly used mechanisms in the medical or social sciences and could be adapted to keep research under control, and within pre-established boundaries, through monitoring, verification and reporting processes[39]. Thus, overall, research governance is essential in prohibiting any bad behavior that might jeopardize procedural justice or increase the risk of mitigation deterrence and unilateral deployment.

### 5.1.2 Cooperation and collaboration

The second minimum requirement for solar geoengineering governance is the establishment of cooperative and collaborative mechanisms, both in research and between countries. Indeed, governance mechanisms that focus on providing these fundamental elements are extremely instrumental in ensuring procedural justice, while preventing mitigation deterrence and especially unilateral deployment. For instance, cooperation and collaboration require some sort of participatory processes, thus satisfying criteria of procedural justice. Similarly, building and stabilizing cooperative relationship in the field of solar geoengineering would avoid the occurrence of unilateral, uncoordinated deployment of solar geoengineering.

[39] Billy Williams RFF Conference panel: "*Capacity building for competent, just, and inclusive decision making*" (*Solar geoengineering Futures*, 2023)

From a research perspective, cooperation and collaboration in solar geoengineering research have the potential to build shared knowledge and trust in the academic community. Marion Hourdequin listed the founding of international cooperation and coordination in solar geoengineering research a priority area for governance[40]. Thus, in the field of solar geoengineering, scientists across the world should collaborate and share findings to build a common understanding of the risks and challenges related to solar geoengineering technologies, and governance mechanisms should help arrange this knowledge exchange. What often happens in academia is the formation of enclosed research centers where the collaboration with outside circles is lacking, as a result this compartmentalization might prevent precious knowledge exchange and create research duplicates[41] (as the case of the individual level of mitigation deterrence analyzed in chapter 4) Therefore, there is a necessity for researchers to work closely together and enhance research collaboration on solar geoengineering technologies[42].

From a political standpoint, establishing a collaborative environment between countries would be extremely beneficial for multiple reasons. According to the authoritative assessment by Florin et al. (2020) a main challenge for solar geoengineering governance relates to security and defense issues that might rise by a large scale and deliberate solar geoengineering deployment. So, to avoid solar geoengineering becoming a security threat, the authoritative assessments stress the need to establish international cooperation. This would allow a transparent and continuous share of knowledge and information and avoid escalation dynamics in case of an uncoordinated solar geoengineering deployment. Additionally, the National Academies of Science (2021) report places cooperation as an essential element for solar geoengineering governance. Through cooperative arrangements countries would be deterred from considering unilateral deployment of solar geoengineering technologies as the information and the state-of-knowledge would be public and shared between states.  Thus, building solar geoengineering cooperation, and strengthening climate coordination between countries, would avoid risks of uncoordinated deployment, rivalries between competing countries, or escalation into armed conflicts[43]. Lastly, building cooperative relationship

[40] Marion Hourdequin, RFF Conference panel: *"Capacity building for competent, just, and inclusive decision making*" (*Solar geoengineering Futures*, 2023)
[41] John Moore, RFF Conference panel: *"Biophysical impacts: climatic & non-climatic risks and benefits"* (*Solar geoengineering Futures*, 2023)
[42] Ibid.
[43] Joshua Horton, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar geoengineering Futures*, 2023)

between researchers and countries is also helpful in bridging the knowledge gap between the Global North and the Global South by transferring expertise between these two macro-areas.

### 5.1.3 Communication

The issues and challenges linked to the three core concepts of this thesis will most likely shape and determine the future developments of solar geoengineering governance. Therefore, how these are communicated and how the technology is being framed is particularly important. So, the last minimum requirement of solar geoengineering governance is communication, which emerged as an essential tool in the data collection of each of the three core concepts of this thesis. For example, the data gathered from the conference observation revealed communication as a central element to ensure procedural justice and avoid mitigation deterrence and unilateral deployment. Indeed, communication is helpful in ensuring engagement in the processes, in providing and sharing information of the functioning, risks and opportunities of solar geoengineering technologies, and finally, it is fundamental when building meaningful cooperative relationships between countries, who need to talk and trust each other, and this can only be achieved through strong communication networks. For instance, when it comes to scientific research and its new fields, like the one of solar geoengineering, communication is essential to share findings and make sure they can be understood by policymakers and the public. Therefore, it is governance's role to ensure the communication of solar geoengineering happens at high standards, while avoiding misinformation and misinterpretation (*Solar geoengineering Futures*, 2023).

Through an efficient communication style, experts and policy makers would be able to gain the public's attention and support, without for example scaring them. Indeed, during the RFF Conference, numerous panelists expressed serious concerns regarding the use of fear over climate change or solar geoengineering technology to spur climate action or technology deployment[44]. Instead, by taking people along the way through an effective communication strategy is possible to convey a true image of solar geoengineering technologies, highlighting both the strengths and the weaknesses of a climate intervention. In this way, by enhancing policymakers and the public's awareness of the technology, future solar geoengineering governance frameworks and decisions can be established with a clear understanding of what these technologies truly entail (Burns et al., 2016; Raimi et al., 2019). For instance, effective

[44] Talbott Andrews, RFF Conference panel: "*Would solar geoengineering crowd out emissions cuts? The moral hazard risk examined*" (*Solar geoengineering Futures*, 2023)

communication would ensure the involvement of researchers and the public from the Global South in the debate, particularly if findings are presented and conveyed in a manner relevant to their unique needs and perspectives. Moreover, empowering individuals to make informed choices through communication is crucial to foster agency in solar geoengineering and climate governance as well[45]. Thus, communication should not only disseminate information but also facilitate dialogue by inviting diverse perspectives and actively addressing communication barriers (e.g., address cultural and social divides, talk constructively human-to-human, use art and other means of communication and expression to build a constructive public dialogue on solar geoengineering technologies)[46].

In addition, communicative processes are fundamental and instrumental to ensure the presence of the previous two minimum requirements of solar geoengineering governance: research governance and cooperation. For instance, through ongoing communication between countries is possible to build a relationship of trust, empathy and understanding which would help build cooperation and collaboration in the field of climate action and solar geoengineering (Brandstedt & Brülde, 2019; MacMartin et al., 2019; Parker, 2014). Similarly, communication in research is crucial in avoiding the pursuit of research out of the public eye and that the findings are shared and divulgated to outside academic worlds (CSIGG, 2023). For example, some panelist at the RFF Conference suggests considering the IPCC as a model for effective communication in the field of climate change[47]. They advocate for the IPCC to embrace its role as the leading science-based organization on climate change and interact with the solar geoengineering community to produce an international assessment on solar geoengineering, which would compensate the scientists' terrible job in communicating the impacts of solar geoengineering[48]. Also the latest UNEP's authoritative assessments on solar geoengineering calls for a scientific review process of the state-of-the-art as an essential course of action for future research and governance developments in the field (UNEP, 2023). Therefore, through effective communication, governance of solar geoengineering would be able to reach a global

[45] Julie Arrighi, RFF Conference panel: "*Capacity building for competent, just and inclusive decision making*" (*Solar geoengineering Futures*, 2023)
[46] Julie Arrighi, RFF Conference panel: "*Capacity building for competent, just and inclusive decision making*" (*Solar geoengineering Futures*, 2023)
[47] Daniele Visioni, RFF Conference panel: "*Biophysical impacts: climatic and non-climatic risks and benefits*" (*Solar geoengineering Futures*, 2023).
[48] Douglas Mac Martin, RFF Conference panel: "*Solar geoengineering's place within the broader climate strategy portfolio*" (*Solar geoengineering Futures*, 2023).

understanding, consensus and judgement of solar geoengineering technologies that would help correctly manage and decide the appropriate role of these technologies.

In summary, research governance, cooperation and collaboration and communication combined would establish solid governance grounds for the novel field of solar geoengineering. Undoubtedly, it would be possible to include additional elements that would be of use in the field of solar geoengineering governance, however, these are the one that have the highest potential to ensure procedural justice, while avoiding mitigation deterrence and unilateral deployment.

## 5.2 THE CORE CONCEPTS' RELATIONSHIP WITH GOVERNANCE

Governance frameworks for solar geoengineering technologies have the power to ensure procedural justice, while avoiding mitigation deterrence and unilateral deployment. But which factors merit our attention to successfully reach this objective? How would this work? What are the tools at governance's disposal?

### 5.2.1 Mitigation deterrence

As far as mitigation deterrence is concerned, a first governance maneuver would be to focus on the 'undone science', for example by increasing the research into the phase out from fossil fuels or into more clear pathways to reach net zero[49]. By enriching the research output in those areas, solar geoengineering technologies might become unnecessary or unwanted, and this would be highly beneficial in contrasting the risk of mitigation deterrence. Additionally, steering the conversation on solar geoengineering away from vested interests, like those of the fossil fuels industry, would likely reduce the risk of mitigation deterrence (D. McLaren, 2016; Reducing the Risks of Climate Overshoot, 2023; J. L. Reynolds, 2019). Indeed, in the paper by Wagner & Zizzamia (2022) vested interests combined with the global scope of solar geoengineering are considered a unique global governance challenge.

Another significant challenge in solar geoengineering's governance is associated with the ongoing academic investigation into the risk of mitigation deterrence. Considering the persistent academic focus on downplaying concerns about mitigation deterrence, as well as the

[49] Holly Buck, RFF Conference panel: *"Important next steps for policy and research: a solar geoengineering research agenda for the next decade"* (*Solar geoengineering Futures*, 2023).

critique of the individual level of mitigation deterrence discussed in the previous chapter, it is imperative for governance to acknowledge and address this line of reasoning. This can be achieved by avoiding pressuring individuals and using fear as a motivator for climate action[50]. For instance, research has shown that a more dangerous outcome than a reduction of mitigation efforts is individuals completely disengaging and ending all mitigation actions because they feel overwhelmed and hopeless about finding a viable solution to global warming[51]. Consequently, the approach in which research on mitigation deterrence is conducted holds implications for the future governance structures of solar geoengineering, and it would be in governance's best interests to monitor research developments in this area.

Finally, there are two additional methods that could prevent mitigation deterrence through governance mechanisms. The first method is coupling development and deployment of solar geoengineering technologies with appropriate levels of mitigation and adaptation. According to this approach, issue-linkage of solar geoengineering would be tight to mitigation goals or parameters that needs to be met before being able to deploy or participate in cooperation and decision-making processes about the technology (J. L. Reynolds, 2022). The second approach, instead, refers to the presence of mitigation deterrence being deeply determined by framings, perceptions, and particularly by the ill-logics of substitution. As previously critiqued, the way solar geoengineering is presented, whether as a substitution to mitigation or a buy-time instrument, likely determines the risk of mitigation deterrence. Therefore, future governance frameworks could avoid such framings by including the irreplaceability of mitigation as a core criteria of solar geoengineering governance and guiding principle of research. Indeed, as H. J. Buck (2022) highlights "the frame shapes action in the real world; how solar geoengineering is talked about shapes what society chooses to know and not know today; it may also shape the sort of governance we choose for geoengineering, which in turn may shape its outcomes" (p. 2).

### 5.2.2 Unilateral deployment

Also, in the case of unilateral deployment, establishing governance mechanisms would be highly needed and beneficial to prevent dangerous deployment scenarios (Jinnah et al., 2019). Indeed, especially in the authoritative assessments evaluated, it is widely accepted that

[50] Talbott Andrews, RFF Conference panel: "*Would solar geoengineering crowd out emissions cuts? The moral hazard risk examined*" (*Solar geoengineering Futures*, 2023)
[51] Ibid.

governance main priority is to prevent an uncoordinated deployment of solar geoengineering (Felgenhauer et al., 2022; Florin et al., 2020). And it is especially in the field of unilateral deployment where the minimum requirements of governance listed above come into play. Firstly, through research governance is possible to build a transparent narration of the technology, showing not only the benefits but also the negative impacts that solar geoengineering might create (Jinnah et al., 2019). In this way policymakers are well informed and aware of the consequences of deployment. Secondly, a combination of cooperation and communication between countries would reduce the risk of geopolitical tensions and prevent solar geoengineering unilateral developments or deployment (Cherry et al., 2023; Horton, 2011). For example, through international cooperation countries' intentions with the technology would be known, countries would be incentivized to share expertise and build relationship of trust that would prevent solar geoengineering discussions to happen outside of the public eye (CSIGG, 2023). Thirdly, and similarly to mitigation deterrence, governance arrangements by shifting the focus away from solar geoengineering and redirecting it toward other policy options, would reduce the appeal of an uncoordinated deployment.

Preventing unilateral deployment is fundamental and governance would play a crucial role in doing this. However, there are some challenges to overcome. In terms of averting scenarios of unilateral deployment, the RFF Conference identified several governance challenges for potential climate interventions: monitoring, detection, and attribution of impacts (*Solar geoengineering Futures*, 2023). Accomplishing these elements would serve as an effective deterrent against unilateral deployment because countries would be able to detect variations in the climate systems and understand if such changes are the outcome of a natural phenomenon or of solar geoengineering deployment. Additionally, being capable of attributing impacts to a certain country represents a unilateral deployment disincentive, as countries would tend to avoid being blamed for any adverse impact of their intervention to the climate[52]. Future projections of climate change produce another governance challenge, because the prospect of crossing future tipping points might lead towards consensus over the necessity of solar geoengineering and to a premature deployment[53]. In this case, governance should decide on fixed threshold for decision-making, advance research and cooperate as much as possible so

[52] Joshua Horton, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar geoengineering Futures*, 2023)
[53] A. Kim Campbell, RFF Conference panel: "A conversation with right honorable A. Kim Campbell, P.C." (*Solar geoengineering Futures*, 2023)

that if we ever reach a tipping point, we would be able to take well-pounded decisions and avoid further damages produced from a reckless deployment[54]. However, given the current instable and precarious international order reaching and putting into place such governance mechanisms might become an intricate obstacle for governance to overcome. Finally, a governance challenge that has profound implications for unilateral deployment, but also for mitigation deterrence, is the ‘slippery slope’ problem. Often related to solar geoengineering outdoor experiments, the slippery slope describes a situation in which research and experimentation of solar geoengineering might inevitably lead to its deployment causing both mitigation deterrence and unilateral deployment. As for this issue, UNEP’s authoritative assessment acknowledges how solar geoengineering research and experimentation can lead to deployment, and it calls for governance of outdoor experimentations as a useful tool to prevent large-scale deployment (UNEP, 2023). On the contrary, the US Congress report advocates the need for outdoor experiments to improve models understanding of these technologies, without mentioning the slippery slope risk that these experiments might create (OSTP, 2023). This can be a problematic shortcoming of the US Congress report as it undervalues the possibility that small-scale experiments might lead to larger-scale experiments, and it leaves open to interpretation the distinction between what is a small-scale deployment and a regular scientific experimentation (Gupta & Möller, 2019). Furthermore, Daniele Visioni at the RFF Conference emphasized how outdoor experimentation would not help understanding the safety of deployment but rather it would only enhance models robustness of future projections (*Solar geoengineering Futures*, 2023).

### 5.2.3 Procedural justice

The final consideration on the relationship between the core concepts and governance of solar geoengineering regards the role of ensuring procedural justice through governance instruments. First, by focusing on research, solar geoengineering governance should make sure to integrate new and under-represented perspectives and diversify the research community[55]. Particularly, research should target developing countries needs and the regional impacts of these technologies as the uncertainties increase at such small-scale if compared to global ones[56]. Furthermore, there is a need for governance to enhance social sciences research in the

[54] A. Kim Campbell, RFF Conference panel: “A conversation with right honorable A. Kim Campbell, P.C.” (*Solar geoengineering Futures*, 2023).
[55] Marion Hourdequin, RFF Conference panel: *“Capacity building for competent, just, and inclusive decision making*” (*Solar geoengineering Futures*, 2023)
[56] Ibid.

field of solar geoengineering (Aldy et al., 2021; Burns et al., 2016; Florin et al., 2020) and to pursue academic exploration into areas of undone science like the phasing out from fossil fuels or the analysis on how to perfection the interplay between research, the media and policy (*Solar geoengineering Futures*, 2023). So, by governing research, solar geoengineering governance can establish participatory processes and inclusive research methodologies, which are necessary to avoid the power imbalances and build procedural justice.

Governance frameworks could strengthen the agency of developing countries so that they acquire the necessary means to properly engage in scientific research on solar geoengineering and to have enough knowledge to speak for themselves[57]. In this regard, including and recognizing the role of indigenous and local communities' perspectives should become a focus of future governance of solar geoengineering. For example, establishing a genuine intercultural dialogue between indigenous and local communities, scientists, policymakers would enhance the chance of fostering procedural justice in the field of solar geoengineering. In this regard, the Convention on Biological Diversity, on the inclusion of Indigenous people into the solar geoengineering debate, "emphasizes the importance of creating a genuine two-way dialogue, not one that only seeks to ask for consent or denial of the technologies" (CBD, 2012, p. 9). Incorporating these fundamental actors and perspectives in the solar geoengineering debate is essential and an actual challenge for solar geoengineering governance. Indeed, indigenous people participation and engagement require efforts, a further step that ensures this inclusion does not only cover the sharing of information on the technology, but also the building of their capacity and knowledge on climate change. In this way it is possible to make sure their voices are heard, that Indigenous communities have agency and ownership, and that their participation and involvement happens on their own terms. Additionally, the disparity between the Global North and the Global South calls the need for Indigenous peoples to "play an active and directive role in setting research agendas, determining research protocols, carrying out research methodologies, storing and interpreting data, and communicating research findings" (Cameron et al., 2009, p. 357).

Lastly, to ensure procedural justice, governance of solar geoengineering should oversee the decision-making process and make sure that there is a clear separation between the researcher and the policy maker. As already anticipated, in such technocratic contexts it is

[57] Hassan Sipra, RFF Conference panel: *"Capacity building for competent, just and inclusive decision making"* (*Solar geoengineering Futures*, 2023).

common for researchers to hold a considerable degree of power in influencing the decisions and the direction of solar geoengineering technology developments. However, despite a certain interface of communication and exchange should be present, this should not overtake the separation between research and decision-making. "The role of scientist is to carry out the best possible research on all these methodologies and synthesize findings in a way that really meets the needs of policy makers; us as scientists must provide this information, policy decisions should be left to others."[58]. Thus, this should be a good guiding principle of solar geoengineering governance: provide norms and structure to solar geoengineering research so that science is able to inform decision-makers but without overtaking the power of taking the decision on such controversial technologies. In this regard, Pamplany (2020) identifies the principles of beneficence and minimization as procedurally just principles of solar geoengineering that governance should pursue, as such frameworks would ensure a fair risk-benefit distribution and a minimization of research risks.

In conclusion, governance is an essential instrument in ensuring procedural justice, while avoiding mitigation deterrence and unilateral deployment. Overall, the main challenges to consider when trying to reach these goals is for sure to restrain unregulated research through research norms and principles, enhance cooperation and communication both between countries and within the science community, increase participation, inclusiveness and engagement, and finally, avoid any type of misinterpretation of solar geoengineering technology. All this considered, governance of solar geoengineering might succeed in regulating this wicked domain of climate governance.

## 5.3 FORM AND FEASIBILITY OF SOLAR GEOENGINEERING GOVERNANCE

Solar geoengineering and its governance represent a rich field of the debate. Numerous and different opinions have been pushed forward to identify the ideal form of governance for the field of solar geoengineering, but less has been said on its feasibility. In this section, these different perspectives and options of solar geoengineering governance are presented. First, however, it is important to stress how, despite the form of solar geoengineering governance has still not been identified. The only consensus in the scholarship resides over the fact a one-size-fits-all approach would not work for solar geoengineering technologies. Indeed, given that solar

[58] Greg Frost, RFF Conference panel: "*A conversation on the NOAA Earth Radiation Budget Initiative with Greg Frost*" (*Solar geoengineering Futures*, 2023)

geoengineering encompasses different methods, actors and scales, and because of the diverse and transboundary nature of its impact, it would be difficult to cover this diversity through a unique form of governance (J. L. Reynolds, 2019). Additionally, as research in this field continues and it solves or discovers new uncertainties, governance arrangements should be able to continuously adapt, respond to emergent needs and challenges and navigate the complexities of the real world. Therefore, this section reflects on the different forms of governance arrangements in the solar geoengineering field, as well as on the feasibility of these in ensuring procedural justice while avoiding mitigation deterrence and unilateral deployment.

### 5.3.1 Form

Therefore, by avoiding a one-size-fit-all framework, solar geoengineering governance should embrace the fragmentation of the field and include multiple forms of governance, including non-state governance and bottom-up mechanisms. Authoritative assessments, in analyzing solar geoengineering governance, conclude that both formal and informal governance approaches can contribute to shape and regulate this new controversial field (Florin et al., 2020; *Reflecting Sunlight*, 2021; UNEP, 2023). Indeed, soft governance principles developed by non-state actors or researchers, such as voluntary code of conducts, certifications or statements (J. L. Reynolds & Parson, 2020), can provide a first and faster attempt to structure this new field; whereas formal state-led frameworks, enforced through international customary laws and treaties, can be developed at a later stage by drawing inspiration from bottom-up governance tools (*Reflecting Sunlight*, 2021; J. L. Reynolds & Parson, 2020). This diversification would compensate the usual weakness of international governance arrangements and overcome the time-consuming processes required to establish them, while providing governance in this fast-changing field (*Reflecting Sunlight*, 2021). Furthermore, non-state governance would answer to the solar geoengineering governance's need to be adaptive and responsive to new developments in research as this type of governance would not be affected by the lengthy procedures of law formation democratic countries are usually bound to (J. L. Reynolds, 2019). Additionally, given the fact that the current governance landscape of solar geoengineering is characterized by a situation of 'governance-by-default', in which state action is absent and academics hold most of steering power of solar geoengineering developments (J. L. Reynolds & Horton, 2020; J. L. Reynolds & Parson, 2020; J. Reynolds & Wagner, 2020), non-state governance can avoid the over-reliance on science and provide order to the field until state-led governance structures are underway. Surely enough, such soft governance arrangements come with limitations. For example, they might lack a certain degree of legitimacy, accountability, transparency and participation, thus reducing their effectiveness (J. L. Reynolds, 2019; J. L. Reynolds & Parson, 2020). Nevertheless, non-state governance is preferable at this stage of solar geoengineering research and development.

As stated by Gupta & Möller (2019), in the field of solar geoengineering there are already some forms of *de facto* governance, and the National Academies of Science report (2021) stress how solar geoengineering governance should start from these existing steering mechanisms. For instance, solar geoengineering research norms like the Oxford, the Tollgate principles, or the more recent ones pushed forward by the American Geophysical Union, represent already established governance frameworks that can be used for guidance to ensure future ethical developments in this new field of climate governance (AGU, n.d.; Zhang & Posch, 2014). There are also other governance mechanisms that could be applied for solar geoengineering governance. For example, the Aarhus Convention or the Escazú Agreement, which ensure participation and access to information and justice in environmental matters, can ensure that solar geoengineering proceeds in a procedurally just way. However, the challenge for these international environmental agreements is that these instruments still do not integrate solar geoengineering into their domains, leaving solar geoengineering out of the scope of formal governance arrangements. For example, the UNFCCC has still not engaged with solar geoengineering, thus highlighting the need for informal bottom-up and soft governance approaches to fill in this gap until international conversation on solar geoengineering are not established.

As for the idea of creating new formal governance arrangements, the RFF Conference debated which platform would be more suitable for solar geoengineering. According to the panelists a possible future regulatory organism for solar geoengineering would look like an arms control treaty rather than an environmental agreement (*Solar geoengineering Futures*, 2023). This for two main reasons: first, environmental agreements are not future oriented, they usually regulate current environmental harms; second, due to the global impact of solar geoengineering deployments and its related geopolitical concerns, an arm control treaty would perform better in governing these technologies. Therefore, as the deployment of solar geoengineering technologies would most likely start from nations states, forms of international global governance, such as multilateral treaties, still represent the best form to restrain countries and govern solar geoengineering developments, especially if coming from United Nations bodies, as they are believed to be the most legitimate to accomplish such goal[59]. However, regarding formal governance frameworks for solar geoengineering, the scholarship remains divided. For example, Joshua Horton remains skeptical on the role of international treaties governing solar geoengineering and believes it would be more hopeful to establish informal cooperative arrangements (*Solar geoengineering Futures*, 2023). This confirms that, at present, the prevailing consensus is that solar geoengineering governance is essential and solar geoengineering governance would involve a combination of both bottom-up regulation in the short term and top-down international treaties in the long term.

Therefore, the need for both informal and formal governance arrangements leads to question which form of governance would best fit the field of solar geoengineering and satisfy the criteria of being adaptable and cautious. In this respect, Reynolds & Horton (2020) believe that polycentric governance might be useful for this emerging field. According to the definition, a polycentric governance system is a situation where there are multiple loci of authority that co-exists and regulate a given field of governance (Gupta et al., 2020; Jinnah et al., 2019). Thus, given climate governance's fragmented nature, a polycentric solar geoengineering governance would best combine non-state actors' regulation with formal arrangements at the regional, national or international level. Additionally, de Ridder et al. (2023) believe that the need to ensure procedural justice in solar geoengineering would be best achieved with such polycentric arrangements. Indeed, these loose and multiple centers of authority would include and incentivize participation of different regulatory frameworks. As far as mitigation deterrence and unilateral deployment are concerned, the scholarship does not agree or provide a best governance framework to avoid such challenges. Probably, given that mitigation efforts are internationally agreed, and solar geoengineering is a global changing technology that comes with geopolitical and security issues, an international multilateral agreement would best prevent the emergence of these challenges. However, since currently there is no binding international treaty that explicitly covers solar geoengineering and there is a pressing need to have governance arrangements right now and it is likely that these technology are going to be covered by an extension of existing treaties (Macnaghten & Szerszynski, 2013). For instance, international treaties applicable to SAI that could be extended are the Convention on Long-range Transboundary Air Pollution, the Vienna Convention for the Protection of the Ozone

[59] Elizabeth Chalecki, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar geoengineering Futures*, 2023)

layer, the Environmental Modification Convention, or in the realm of customary laws, the principle of the polluter pays could help regulate solar geoengineering (Rabitz, 2016).

All this considered, when it comes to identifying the form of governance that could help regulating solar geoengineering and ensuring that its research and development is done following the preconditions of procedural justice, or by avoiding mitigation deterrence and unilateral deployment, there is no unique answer. Instead, it is likely that solar geoengineering governance will be established on a range of different scales, actors and include various approaches (MacMartin et al., 2019; Parker, 2014). Therefore, this leads to consider the feasibility of governance arrangements in ensuring procedural justice and prevent mitigation deterrence and unilateral deployment in the real world.

### 5.3.2 Feasibility

In the previous section different governance forms and arrangements were introduced and described in the framework of solar geoengineering. However, as the evidence suggests, in the solar geoengineering debate there is no fixed or certain opinion on the most suitable form of governance. This naturally brings questions of the governability of solar geoengineering and weather it is feasible in the current socio-economic and political system. Reflecting on the feasibility at this stage of research is important to understand whether governance can successfully navigate solar geoengineering's complexity given the three core concepts' preconditions and challenges. Here feasibility refers to the likelihood of solar geoengineering governance in ensuring procedural justice while avoiding mitigation deterrence and unilateral deployment, an ambitious goal that might not be achievable in practice. Indeed, when it comes to ensuring procedural justice and avoiding mitigation deterrence and procedural justice there are certain requirements that need to be met in practice, but in a real-world setting is this really feasible? And in case it is not, what does it leaves us in? This section tries to answer to these questions by addressing form and feasibility in each of the core concepts of this thesis.

Chapter 4 outlined the state-of-the-art for mitigation deterrence, unilateral deployment and procedural justice and underlined the different elements and challenges emerging from these concepts. Chapter 5 instead highlighted the specific governance requirements the three concepts need to be established or prevented. For example, it was said that mitigation deterrence varies according to scale, that its empirical evidence is unbalanced toward the individual level and that it is likely to become a real threat according to the framings used.

Thus, mitigation deterrence requires a governance that focuses on different levels, that is careful of how the technology is framed and perceived. Similarly, unilateral deployment confirmed to be a geopolitical problem in which different actors might see an opportunity to deploy. In this regard, to avoid unilateral deployment governance should focus on promoting cooperation and transparency in the field. As for procedural justice, the evidence stresses how currently the research on solar geoengineering lacks participation, inclusivity and consent from underrepresented voice; and in this case governance arrangements could reduce and tackle this shortcoming if designed according to criteria of procedural justice. So, each concept comes with challenges that ideally can be addressed with governance, however this cannot be done so easily in the real world. Indeed, keeping control on solar geoengineering framings and developments, paying attention that this technology is pursued in the society and planet's interest, is unlikely to come as straightforward in the current international system. On the feasibility of solar geoengineering governance, Richard Owen and his paper "*Solar Radiation Management and the Governance of Hubris"* (2014) extensively analyzes the governance of this emerging technology within democratic systems and comes to two conclusions. First, according to Owen, solar geoengineering should not be seen as only a technology but as a political artefact entangled with different political and moral dimensions. Consequently, solar geoengineering purposes, motivations and impacts becomes sites of politics. Second, in evaluating the feasibility of solar geoengineering governance, Owen believes that it would be possible to ensure future ideal technology developments through governance arrangements, however, in his view, this will require agreements, institutions and a culture change that cannot be guaranteed. Some may argue that the present struggles within the international community in reaching global consensus on mitigation signal the failure of democratic governance and inevitably suggest the ungovernability of solar geoengineering. However, despite this negative perspective, it is still too early to give up on solar geoengineering governance. At this early stage of solar geoengineering, governance structures can make sure this technology is pursued in a democratic and inclusive way if researchers and policymakers are willing and open to pursue that.

## 5.4 CONCLUDING REMARKS

This second empirical chapter answers the second sub-research question of this thesis, and it develops the governance implications drawing from the conclusions of the previous chapter. Some final remarks are outlined below and summarized in *figure 8*.

This new climate governance field requires, as a first step to ensure procedural justice while avoiding mitigation deterrence and unilateral deployment, three elements: research governance, cooperation and collaboration, and communication. First, as research is not neutral, research governance can ensure that research into solar geoengineering is properly performed and done in the public's interest. Second, cooperation and collaboration, both in academia and between countries, would ensure a continuous exchange of knowledge and it would build the necessary trust to deter any unilateral deployment. Third, communication is fundamental to avoid misinterpretation and misinformation of solar geoengineering by ensuring engagement, cooperation and a clear understanding of solar geoengineering.

Solar geoengineering governance can avoid mitigation deterrence through different instruments. For example, by focusing on undone science, by using the correct framings and by employing issue-linkages, the risk of solar geoengineering becoming a deterrence of mitigation is greatly reduced. Additionally, with the application of solar geoengineering governance's minimum requirements it would be possible to monitor the research flow into the problem of mitigation deterrence and avoid the manipulation from vested interests. Similarly, avoiding unilateral deployment can mostly be achieved with cooperation and communication between countries. By sharing knowledge and establishing cooperative relationships it is possible to build trust between countries and reduce the risk of uncoordinated deployment. Particularly, solar geoengineering governance should focus on monitoring, detection and attribution of impacts as they represent the best approach to identify and block unilateral deployment. Furthermore, research governance could prevent a slippery slope of solar geoengineering experimentation leading towards premature deployment. Lastly, governance of solar geoengineering can ensure requirements of procedural justice are met in the research and developments of solar geoengineering. Especially, governance can foster the diversification of research and the inclusion of diverse perspectives, while maintaining a balanced science-policy interface. Also, solar geoengineering governance through capacity building and knowledge exchange can establish an intercultural dialogue and enhance participatory processes.

At last, when evaluating the most suitable governance framework for solar geoengineering is important to avoid one-size-fits-all approaches. Instead, good solar geoengineering governance should embrace the diversity of the field by combining both informal, bottom-down regulation and formal, top-down governance (e.g., polycentric governance). In general, identifying the best regulatory approach to solar geoengineering and how governance should look like in the real world is not an easy task. As of now, what emerges is that by securing the three minimum requirements of solar geoengineering governance and by integrating solar geoengineering into the existing governance instruments it would be possible to reach performative governance arrangements.

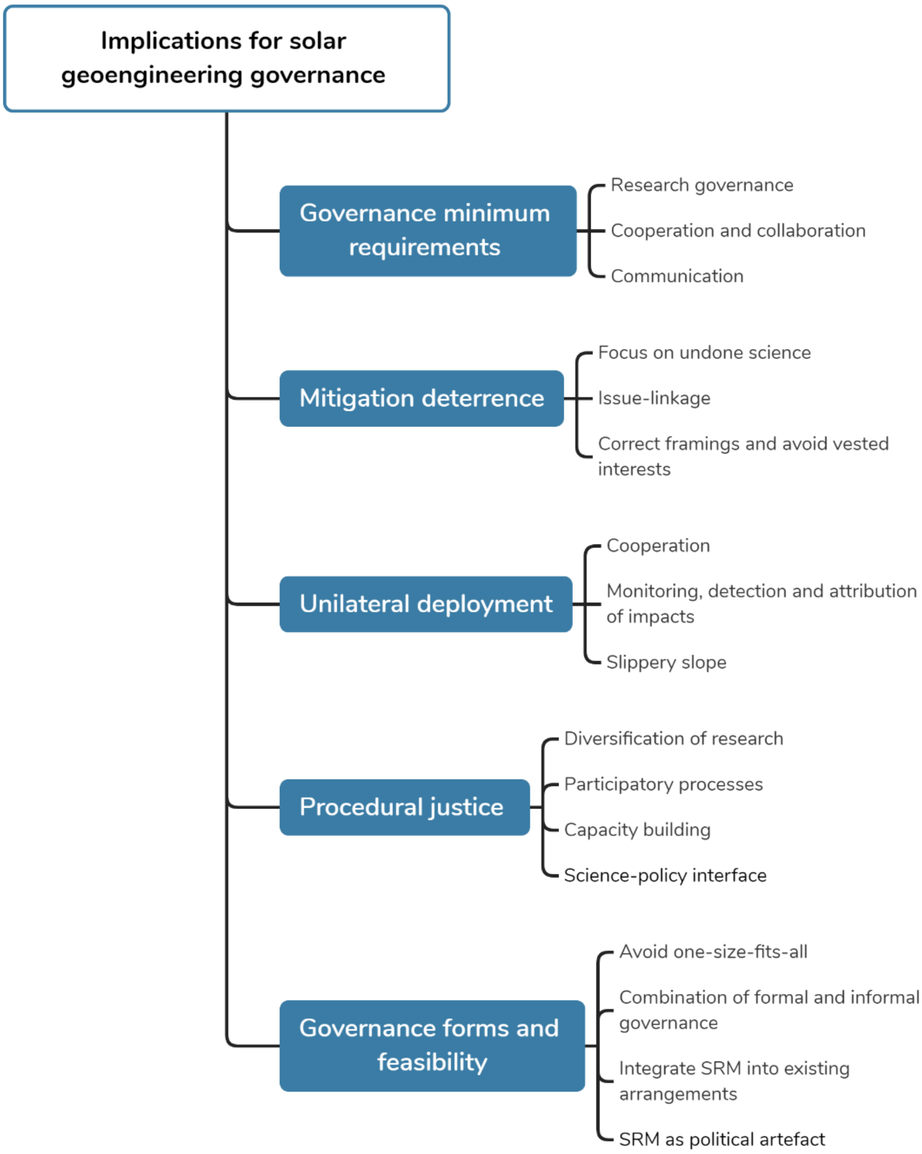



*Figure 8: Summary of empirical Chapter 5 – Implications for solar geoengineering governance*

# 6 DISCUSSION AND CONCLUSION

This chapter brings together some final considerations and reflects upon the research process. Firstly, the research questions are comprehensively answered. Secondly, remarks on the methodology and theoretical framework are outlined. Lastly, the final paragraphs wrap up the thesis and present some future pathways of solar geoengineering in the climate governance landscape.

## 6.1 ANTICIPATE BUT WITH A FOOT GROUNDED IN THE PRESENT

This section answers the overarching research question: *What are the core contestations in solar geoengineering scholarship and what implications do these have for design and feasibility of anticipatory governance?.* This question addresses an important and complex issue, as solar geoengineering involves potentially large-scale interventions in the Earth's climate system, with significant environmental, social, and political implications. Thus, anticipatory governance, in this context, would involve designing strategies and structures to anticipate and address the risks, uncertainties, and ethical considerations associated with solar geoengineering research and deployment before they become urgent or irreversible. Here the results and conclusions from the two empirical chapters are brought together to provide a complete picture of the anticipatory governance of solar geoengineering.

The scholarship's appeal for solar radiation modification options, especially regarding SAI, is quite understandable. In a perfect world scenario solar geoengineering would represent a valid alternative to ensure a concrete and a fast-cooling effect, while maintaining current carbon-intensive economic systems and lifestyles. Additionally, lengthy and stressful international negotiations would not be necessary as scarce mitigation efforts could be bypassed with the use of solar geoengineering. However, given the complexities of the real world, and the numerous challenges connected with solar geoengineering, taking decisions over these technologies is extremely more complicated than in such perfect world settings. Globally intervening in the climate system is no easy fix to the climate emergency. Therefore, the research questions of this thesis are relevant in avoiding such perfect world scenarios as they provide a clear picture of the current knowledge on solar geoengineering, especially by focusing on its most controversial aspects regarding mitigation deterrence, unilateral deployment and procedural justice, and by including the governance response to these challenges.

The first sub-research question looked at the state-of-the-art on mitigation deterrence, unilateral deployment and procedural justice in the solar geoengineering debate, and unpacked their main elements, perspectives and contestations. As they represent the most controversial and debated elements in the academic discussion on solar geoengineering, their operationalization and understanding is crucial to better understand this novel technology and to shape future governance arrangements. The results show how the risk of mitigation deterrence and unilateral deployment should not be disregarded. Any scenario in which the climate intervention brings reduced mitigation or a deployment by a rogue actor must be avoided, as it might bring geopolitical instabilities and environmental damage to an already exhausted planet. Furthermore, when it comes to the procedural justice, the state-of-the-art confirms solar geoengineering as an exclusive field that perpetuates present inequalities and does not adequately engage the public in decision-making processes.

Building up from this evidence, the second sub-research question aimed at navigating the governance implications associated with ensuring procedural justice while avoiding mitigation deterrence and unilateral deployment. The results show that most of the work should be done now, as the awareness on the technology is still at early stages. Both scientific research and governance arrangements should be pursued to best respond to the climate crisis. This could help ensure that conversations about solar geoengineering stay grounded in the progress achieved so far in mitigation efforts, potentially avoiding more problematic directions. To ensure procedural justice while preventing mitigation deterrence and unilateral deployment, any future development of solar geoengineering must be done in a just, inclusive manner, and in a way that a reduction of mitigation efforts or an uncoordinated deployment are not seen as viable option in the fight against climate change.

In this regard, the design of anticipatory governance is fundamental in governing the contested field of solar geoengineering and ensure that future solar geoengineering research or deployment is done in a procedurally just way that avoids mitigation deterrence and unilateral deployment. As this governance framework provides useful tools to govern novel controversial technologies, including solar geoengineering methods, anticipatory governance should be designed in a way that is adaptable to new discoveries and in a way that is at the same time restrictive and enabling. The idea of “governing to enable or governing to restrict” as exemplified by Gupta et al. (2020) gives a clear picture of the anticipatory value of solar geoengineering. According to which futures researcher or policymakers envision as plausible, their imaginaries are likely going to determine the governance response and outcomes, as well as the role of solar geoengineering as a policy option in the climate governance landscape. The need to govern uncertain futures requires the establishment of adaptable steering mechanisms in the present. In anticipating futures where novel technologies might reduce the focus from mitigation, represent a geopolitical threat, or further exclude underrepresented voices, anticipatory governance can develop the necessary mechanisms to avoid such futures. The stakes are too high, and our planet cannot afford such destructive scenarios, thus, navigating its governance implications through an anticipatory attitude is crucial. However, always taking decisions with the future in mind can result in counterproductive results that might overlook present needs or challenges. Sometimes future problems derive from present shortcomings, for example present inequalities might become impossible to tackle in the future, if not promptly addressed in the present. Vervoort & Gupta (2018) say that "an imagined future overwhelms the present" (p. 2) thus explaining the title of this section which recalls to the need of establishing a balance between imagining the future and governing the present. As the future is uncertain, anticipatory governance's design should not only be focused on avoiding future risks but also on minimizing present challenges.

## 6.2 THEORETICAL AND EMPIRICAL CONTRIBUTION

The debate on solar geoengineering can be confusing, because of the different perspectives and contestations. Moreover, "the particular characteristics of solar geoengineering technology, combined with worsening climate change, along with our current international political environment, suggest that solar geoengineering might emerge in a non-ideal, non-optimal, politically chaotic manner" [60] . These characteristics might be overwhelming, especially for policymakers called to implement efficient policies to manage the climate emergency and who struggle to navigate this field complexity. Thus, this thesis merges together the state-of-the-art on mitigation deterrence, unilateral deployment and procedural justice and draws the governance implications that should be accounted for the design of future anticipatory governance arrangements. This research project empirically contributes to the academic debate on solar geoengineering by bringing together the current

[60] Tyler Felgenhauer, RFF Conference panel: *"Plausible non-optimal near-term solar geoengineering scenarios"* (*Solar geoengineering Futures*, 2023)

state of knowledge on the concepts of mitigation deterrence, unilateral deployment and procedural justice, so that future solar geoengineering research and governance can be directed toward more ideal pathways. In the debate on solar geoengineering, mitigation deterrence and unilateral deployment concepts are highly contested, whereas considerations on procedural justice are widely under analyzed, thus requiring further inquiry. Therefore, as this thesis identifies different perspectives and contestation within the debate on solar geoengineering, it should be approached as a sort of guide for future research and development. It provides more clarity on the debate on solar geoengineering and gives a sense of direction for policymakers and researchers. For example, by applying some of the considerations and insights included in this thesis, such as the governance minimum requirements, it could help policymakers in avoiding some challenges linked with solar geoengineering, and other novel technologies.

Additionally, this thesis serves to critically highlight the embedded nature of solar geoengineering within the perpetuation of historical injustices and inequalities, reflecting the characteristics of capitalist, colonial and patriarchal societies. Anticipatory governance involves tracing the origins of imaginaries and steering mechanisms, a task of particular relevance when considering solar geoengineering. For example, critics have underlined how these global climate intervention technologies are usually manifestation of a patriarchal approach to climate governance (Friedrich, 2023). The field of solar geoengineering is dominated by men and the opinions and contributions from women or Indigenous women are rather marginalized or non-existent. Therefore, critically engaging with solar geoengineering means also understanding the logics and discourses behind such controversial proposal, which often do not reflect women, Indigenous women or marginalized people's preferences and needs. Furthermore, the scientific debate on solar geoengineering is far from being neutral; such technologies are constantly manipulated and influenced by a wide variety of powers and interests. The thesis findings reveal how the evidence in support of solar geoengineering is often biased, with support stemming from solar geoengineering advocates, northern-centric scientific communities or greedy elites and corporate powers reluctant to sacrifice their lifestyles and overly reliant on technological fixes (Surprise, 2020b). Proposing solar geoengineering technologies as the panacea for the climate crisis perpetuates the same patterns that have brought the planet to its current state. Attempting to manipulate climate systems without addressing the underlying causes of the global emergency replicates past wrongs and is fundamentally hypocritical. Thus, it becomes imperative to ensure procedural justice in the realm of solar geoengineering, guarding against mitigation deterrence and unilateral deployment.

## 6.3 METHODOLOGICAL AND THEORETICAL REFLECTION

This section presents a reflection on the methodological and theoretical choices. Reflecting upon these is fundamental to identify the strengths and limitations of this research project and highlight the internal and external validity of the thesis.

This research is focused on three core concepts: mitigation deterrence, unilateral deployment and procedural justice, which represent some of the most contested themes in the solar geoengineering debate. Indeed, in the scholarship these core concepts are surrounded by diverse and often diverging perspectives, which make solar geoengineering a complicated field to fully grasp. Therefore, deciding to base this research project on these three elements within the debate revealed to be a good conceptual choice. By addressing their contestations and main challenges it is possible to include in the analysis a wide range of issues that can arise from solar geoengineering. Additionally, as the implications that emerge from these concepts' analysis will likely shape the governance arrangements, choosing mitigation deterrence, unilateral deployment and procedural justice as focus enabled to identify the feasibility of governance in this field. In this regard, when analyzing the governance implications of novel technologies, the theoretical perspective of anticipatory governance best describes the potential role of regulatory frameworks in governing present or future technological innovations. The anticipatory approach provides useful starting points upon which building the necessary governance frameworks for emerging technologies, which might have the power to completely change the governance landscape and the decision-making process in the coming years. Whether solar geoengineering will be pursued or not, the prospect of its potential use as a climate policy option, its global scale and possible positive or negative future effects, makes it a perfect testing ground to establish anticipatory governance approaches to ensure safe pathways for solar geoengineering developments. However, limiting the evaluation of solar geoengineering to the anticipatory field of governance might impede a complete assessment of this technology and lead to anticipatory ruination or a disregard towards the present. A possible alternative theoretical framework that could have been applied to this thesis is that of 'sociotechnical frameworks', which Sovacool et al. (2023b) conceptualize as an approach that include the technicalities of novel technologies (e.g., infrastructures, hardware) and combines them with financial, economic, socioenvironmental, political and institutional dimensions.

As far as the methodology is concerned, to comprehensively gather the state-of-the-art and the governance implications relating to mitigation deterrence, unilateral deployment and procedural justice three different data sources were selected. Data coming from a literature review, authoritative assessment and conference observations were combined to answer the research questions of this research project and analyzed through a critical interpretative review approach. The data sources were sufficient to gather enough information to adequately answer the sub-research questions. For example, the RFF Conference gathered some of the most prominent scholars in the field of solar geoengineering, reducing the need to design personalized interviews. Similarly, the authoritative assessments provided essentials insights to collect the perspectives of international organizations, governments and research institutes. Finally, the literature review helped build the background information on solar geoengineering and fill in the gaps that could not be filled by the authoritative assessments and the conference. As for the data analysis approach, it was chosen to provide a critical lens to the study of solar geoengineering technologies and the interpretative review allowed to have a certain degree of flexibility in identifying the data and analyze them.

This methodological approach, however, comes with two main limitations. First, a time constraint prevented the establishment of a comprehensive, exhaustive reconstruction of the state-of-the-art of solar geoengineering from its first appear in academic debates till now. Indeed, dedicating additional time on collecting data and information would have helped in presenting a more complete picture and overview of solar geoengineering. A second limitation is linked to the data analysis used. Using a critical framework might have led to subjectivity biases in which the unconscious preferences of the author might have influenced the objectivity of the analysis. Indeed, this author personal point of view and perception of solar geoengineering technology might have affected the interpretation of the data collected. Additionally, it is necessary to also point out how this author's positionality, as a white woman from the Global North, might have influenced the analysis. Lastly, some criticism must be forwarded in regard of the data source. First, the authoritative assessments sometimes adopted a limited approach when dealing with mitigation deterrence, unilateral deployment and procedural justice. For example, reports coming from important organization like UNEP, the US Congress or the National Academies of Science, who have a considerable amount of power and a *de iure* governance authority, present a very limited evaluation of the risks linked with the three core concepts of this thesis. This can be considered a wasted opportunity that could have helped in stimulating government's attention and participation in solar geoengineering discussions. Secondly, it has to be mentioned the fact that the conference observed was organized by an environmental think-thank based in the US which, according to Surprise & Sapinski (2023), has links with elite universities and corporations and takes a pro-market approach to environmental problems.

Finally, some reflections on this thesis external validity must be made. Indeed, despite this research project being concentrated on solar geoengineering, and most of its results regard strictly the case of mitigation deterrence, unilateral deployment and procedural justice, some of the considerations presented could also be applied to other novel technological fields, especially those referring to the governance implications. Indeed, technological innovations outside the realm of solar geoengineering might also create similar governance challenges that needs to be mitigated through appropriate governance mechanisms. For example, new technologies like artificial intelligence, gene editing or nanotechnologies have recently emerged into the public discussions without proper governance regulations. These technologies' novelty combined with their potential negative side-effects are very similar to the issues linked with solar geoengineering if left ungoverned. Therefore, some research results contained in this thesis can be generalized and upscaled to other technological domains. For instance, the minimum requirements of research governance, communication, cooperation and collaboration, with the future oriented attitude of anticipatory governance, it would be possible to established structure and order in these new innovative fields and reduce their risks. Certainly, it's important to recognize that new technologies bring their own set of considerations. Treating them as a uniform issue with a one-size-fits-all solution might be just as harmful as leaving the field unregulated. Therefore, while it's possible to apply some findings from this thesis to other technological areas, it should be done cautiously, considering their distinct characteristics and obstacles.

## 6.4 CONCLUSION AND WAY FORWARD

Global warming can be considered one of the most pressing issues our planet is facing today. However, many governments are unable to adopt effective and adequate policies to prevent a point of no return. In this worrying context, solar geoengineering is presented as a possible escape strategy that could produce a cooling effect in a fast and inexpensive way. Novel technologies has so far improved our living conditions and allowed us to develop with unprecedented rates. However, the promise of solar geoengineering sounds idyllic and, in our imperfect, intertwined and complex world it is unlikely to reach such an easy exit. New technological innovations come with serious governance, ethical and environmental challenges that must not be undervalued. Particularly, solar geoengineering could deter mitigation of anthropogenic GHG emissions; it could be pursued by an individual country without the agreement of the international community; and it can also be deployed without public participation and consent. These three challenges, linked specifically to mitigation deterrence, unilateral deployment and procedural justice, have been the motive to design this research project in a way to fully grasp their controversial dimensions and initiate governance arrangements.

Solar geoengineering remains a new realm of climate governance that needs further development, research and especially governance. What I recommend for the future of solar geoengineering is that policymakers should enter the discussions on this technology, so that they can ensure that any future climate policy is taken in the public interest and that the decarbonization of our economies and lifestyles remains our governments' priority. Furthermore, scientists and international organization dealing with climate change should initiate an international scientific assessment to reach a global understanding and consensus over solar geoengineering as soon as possible. Such a comprehensive assessment should include both the natural and social sciences, as well as Indigenous knowledge and perspectives to provide a full picture of the impacts of solar geoengineering to our environment and societies. Any future development that does not lead to decarbonization, it does not include all the affected parties and underrepresented voices, and prevents the establishment of international cooperative relationships, should be avoided as potentially destructive and detrimental in addressing the climate emergency.

In conclusion, future pathways of solar geoengineering should acknowledge the social complexity of deploying planetary changing technologies. Solar geoengineering, with its challenges and risks, is already entering the climate governance landscape, and policymakers and scientists are highly unprepared to adequately deal with such controversial technology. What will be the role of solar geoengineering still need to be determined. Now it is time to engage with this new field and implement the necessary precautions, so that if solar geoengineering will ever be used, it is going to be in safe and governed way. As there is no perfect solution when dealing with solar geoengineering, we must do what is in our best to secure a safe and resilient future when fighting the climate crisis. The time is already running out; the options for halting future global warming are already there, and it is up to us to best use this knowledge and build a better future.

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# 8 ANNEX

## 8.1 TABLE 1: SEARCH BY KEYWORD

| | Definition | Search by keyword |
|---|---|---|
| **Mitigation deterrence** | The risk that solar geoengineering technologies reduce mitigation efforts. | “Mitigation deterrence” – “deterrence” – “moral hazard” |
| **Unilateral deployment** | The possibility for a country or a coalition of countries to unilaterally deploy solar geoengineering against the will of the international community. | “Unilateral deployment” – “unilateral” – |
| **Procedural justice** | Refers to the decision-making process, which to be procedurally just requires fairness, participation, recognition, transparency, representation and access to information and the decision-making process. | “Procedural justice” – “justice” – “decision-making” – “procedural” – “inclusivity” – “indigeneity” – “indigenous” – “global south” – “developing countries” |

## 8.2 TABLE 2: AUTHORITATIVE ASSESSMENTS UNDER ANALYSIS

| Institution | Title | Date | What is it about? |
|---|---|---|---|
| **Florin et al. – (Swiss federal office for the environment, FOEN)** | *“International governance issues on climate engineering – information for policymakers”* | 2020 | The report reviews and compares solar geoengineering technologies to better understand their benefits, opportunities, risks and uncertainties. Additionally, it examines the current legal and institutional landscape of climate engineering governance. |
| **National academies of science** | *“Reflecting sunlight: recommendations for solar geoengineering research and research governance”* | 2021 | This consensus study report represents an update of the 2015 assessment, and it provides recommendation on how to establish a research program for solar geoengineering. |
| **Felgenhauer et al. – (Carnegie climate governance initiative)** | *“Solar radiation modification: a risk-risk analysis”* | 2022 | The report focuses on examining the tradeoffs related to solar geoengineering: its potential in reducing climate risks and at the same time introducing new risks. The report employs a risk-risk tradeoff framework to compare a world with solar geoengineering and a world without. |
| **Office of science and technology policy (OSTP)** | *“Congressionally mandated research plan and an initial governance framework related to solar geoengineering”* | 2023 | This Congressionally mandated report provides a research plan for solar radiation management intervention. It gives an idea of what type of research should be performed to improve our understanding of solar geoengineering. |
| **Climate Overshoot Commission** | *“Reducing risks of climate overshoot”* | 2023 | This report provides recommendations on different approaches to avoid climate overshoot scenarios. Among these, it analyzes solar geoengineering technologies and advocates for a moratorium as well as the continuation of research and discussions on solar geoengineering. |

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| **United Nations Environmental Program (UNEP)** | *"One atmosphere: an independent expert review on solar radiation modification research and deployment"* | 2023 | The report presents a review of the state of scientific research on solar geoengineering, by taking into consideration environmental, social, economic, and political aspects. It stresses the elevated level of uncertainty and the insufficient level of knowledge to make well-informed decisions. |
| **United Nations Educational, Scientific and Cultural Organization (UNESCO)** | *"Draft report of the world commission on the ethics of scientific knowledge and technology (COMEST) on the ethics of climate engineering"* | 2023 | The UNESCO report addresses the ethics of climate engineering, and it shares some recommendations. |
| **European Union Commission – Scientific advice mechanisms** | *"Scoping paper: solar radiation modification"* | 2023 | Brief paper introducing the debate on solar geoengineering for the European Commission. It presents a way forward for the EU on how to approach this topic. |
| **Centre for sustainability innovation and good governance (CSIGG)** | *"Geoengineering report – policy, research, technology and the future"* | 2023 | This report explores the role of geoengineering as well as its implication in various fields (science, ethics, policy, technology). It aims to understand the possibilities and risks of geoengineering. |

## 8.3 TABLE 3: SCIENTIFIC PAPERS ON MITIGATION DETERRENCE

| Author | Title | Date | Arguments on mitigation deterrence |
|---|---|---|---|
| **Benjamin Hale** | *"The world that would have been: Moral hazard arguments against geoengineering"* | 2012 | - Mitigation deterrence arguments are ambiguous, vague, multilayered and too complicated.<br>- Not self-explanatory, therefore easy to dismiss. |
| **Jesse Reynolds** | *"A critical examination of the climate engineering moral hazard and risk compensation concern"* | 2014 | - Mitigation deterrence arguments should not restrict or halt solar geoengineering research.<br>- Solar geoengineering implementation provides net benefits through substitution. |
| **David R. Morrow** | *"Ethical aspects of the mitigation obstruction argument against climate engineering research"* | 2014 | - The current uncertainty on the technology does not justify a moratorium.<br>- A wise and cost-effective solar geoengineering deployment might justify some reduction in mitigation. |
| **Corner & Pidgeon** | *"Geoengineering, climate change skepticism and the 'moral hazard' argument: an experimental study of UK public perceptions"* | 2014 | - The perception on solar geoengineering deterring mitigation widely depends on worldviews.<br>- The combination between skepticism and wealth, and the prospect of solar geoengineering might lead people to disengage from sustainable behavior. |

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| **Duncan & McLaren** | *"Mitigation deterrence and the 'moral hazard' of solar radiation management"* | 2016 | - The acceptability of solar geoengineering depends on the climate policy goal.<br>- Given the insufficient level of mitigation, the mitigation deterrence argument of solar geoengineering should not be dismissed.<br>- Restricting solar geoengineering research would be detrimental as well (call for governance and responsible research). |
| **Burns et al.** | *"What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for future research"* | 2016 | - Unfamiliarity with solar geoengineering introduces potential biases. |
| **Merk et al.** | *"Knowledge about aerosol injection does not reduce individual mitigation efforts"* | 2016 | - People do not reduce mitigation support after being informed on SAI. |
| **Markusson, McLaren & Tyfield** | *"Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs)"* | 2018 | - Mitigation deterrence is normatively undesirable.<br>- Depends on climate policy goals, framing and poor substitutability. |
| **John Halstead** | *"Stratospheric aerosol injection research and existential risk"* | 2018 | - Mitigation deterrence possibility will likely increase if SAI becomes more mainstream.<br>- Overconfidence in technology and vested interests could deter mitigation. |
| **Clare Heyward** | *"Normative issues of geoengineering technologies"* | 2018 | - Mitigation deterrence can be prevented by avoiding logics of substitution. |

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| **Raimi et al.** | *"Framing of geoengineering affects support for climate change mitigation"* | 2019 | - Mitigation deterrence is a critical concern.<br>- Depends on framing.<br>- Disproved the argument that reading about solar geoengineering increases belief in climate change. |
| **Austine & Converse** | *"In search of a weakened resolved: Does climate-engineering awareness decrease individuals' commitment to mitigation?* | 2021 | - Their study shows solar geoengineering awareness does not significantly weaken climate mitigation efforts.<br>- However, they acknowledge that solar geoengineering is not neutral and requires precautions. |
| **Cherry et al.** | *"Does solar geoengineering crowd out climate change mitigation efforts? Evidence from a stated preference referendum on a carbon tax"* | 2021 | - The study suggests that solar geoengineering may crowd in rather than crowd out mitigation efforts, especially after providing information about solar geoengineering.<br>- Mitigation deterrence depends on worldviews. |
| **Jebari et al.** | *"From moral hazard to risk-response feedback"* | 2021 | - Mitigation deterrence arguments are unhelpful and counterproductive, and we should move to a risk-response feedback framework.<br>- Tandem evaluation of the policy options, avoid substitution of options.<br>- Mitigation deterrence is a moral hazard in itself.<br>- Importance of framing. |
| **Bodansky & Parker** | *"Research on solar climate intervention is the best defense against moral hazard"* | 2021 | - Knowledge on solar geoengineering is necessary to avoid bad future decisions and reduce risk of moral hazard. |

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| **Andrews, Delton & Kline** | *"Anticipating moral hazard undermines climate mitigation in an experimental geoengineering game"* | 2022 | - Moral hazard anticipation.<br>- In the experiment people do not engage in mitigation deterrence.<br>- Mitigation deterrence should not be the first concern. |
| **Cherry et al.** | *"Climate cooperation in the shadow of solar geoengineering: an experimental investigation of the moral hazard conjecture"* | 2022 | - First attempt to analyze collective moral hazard rather than individual.<br>- Evidence rejects the moral hazard argument. |
| **Wagner & Zizzamia** | *"Green moral hazards"* | 2022 | - Mitigation deterrence is linked to the framing of solar geoengineering as a techno-fix. |
| **Harding, Belaia & Keith** | *"The value of information about solar geoengineering and the two-sided cost of bias"* | 2022 | - Mitigation deterrence is the result of over-optimistic bias. |
| **Jesse Reynolds** | *"Linking solar geoengineering and emissions reductions: strategically resolving an international climate change policy dilemma"* | 2022 | - Issue-linkage to prevent mitigation deterrence. |

## 8.4 TABLE 4: SCIENTIFIC PAPERS ON UNILATERAL DEPLOYMENT

| Author | Title | Date | Arguments on unilateral deployment |
|---|---|---|---|
| **Joshua B. Horton** | *"Geoengineering and the myth of unilateralism: pressures and prospects for international cooperation"* | 2011 | - The Author argues against the possibility of unilateral deployment.<br>- There are more incentives in coordinated implementation.<br>- Logics of multilateralism. |
| **Florian Rabitz** | *"Going rogue? Scenarios for unilateral geoengineering"* | 2016 | - The article develops a conceptual framework to analyze unilateral deployment.<br>- It develops different scenarios according to several actors (non-state, small states and great powers).<br>- It concludes that only powerful states are likely to unilaterally deploy. |
| **Parker, Horton & Keith** | *"Stopping solar geoengineering through technical mean: a preliminary assessment of counter-geoengineering"* | 2018 | - Preliminary analysis of counter-geoengineering.<br>- Argues that any power with counter-geoengineering capabilities would have a veto power over any future deployment, thus reducing the risks of unilateral deployment. |
| **John Halstead** | *"Stratospheric aerosol injection research and existential risk"* | 2018 | - The author believe that the risks of unilateral deployment are overstated.<br>- Places value on research to reduce uncertainties and govern the field. |
| **Chalecki & Ferrari** | *"A new security framework for geoengineering"* | 2018 | - Analysis of solar geoengineering technologies through a just war theory.<br>- Just war theory provides a useful framework to restrain unilateral deployment. |

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| **Fruh & Hedahl** | *"Climate change is unjust war: geoengineering and the rising tides of war"* | 2019 | - By comparing climate change to a security threat, the author argue that solar geoengineering represents a justified form of self-defense.<br>- Thus, under future climate change, unilateral deployment is justified according to just-war theory. |
| **Kevin Surprise** | *"Geopolitical ecology of solar geoengineering: from a 'logic of multilateralism' to logics of militarization"* | 2020 | - Argues that solar geoengineering is governed by logics of militarization.<br>- Solar geoengineering would respond to the US strategic interest to preserve their hegemony. |
| **Axel Michaelowa** | *"Solar radiation modification – a silver bullet climate policy for populist and authoritarian regimes"* | 2021 | - Analysis of unilateral deployment of solar geoengineering by populist or authoritarian regimes.<br>- Monitoring systems and effective sanctions are needed to address unilateral deployment.<br>- Populist and authoritarian governments are more attracted to SRM. |
| **Holly Jean Buck** | *"Environmental Peacebuilding and Solar Geoengineering"* | 2022 | - Analysis of solar geoengineering as a peace building instrument.<br>- Environmental peacebuilding should be included in solar geoengineering research. |
| **Sovacool, Baum & Low** | *"The next climate war? Statecraft, security, weaponization in the geopolitics of a low carbon future"* | 2023 | - Security risks associated with climate-technologies: diplomatic or military negotiating tools; objectives for building capacity, control, or deterrence; targets in ongoing conflicts; and causes of new conflicts. |

## 8.5 TABLE 5: SCIENTIFIC PAPERS ON PROCEDURAL JUSTICE

| Author | Title | Date | Arguments on mitigation deterrence |
|---|---|---|---|
| **Svoboda et al.** | *"Sulfate aerosol geoengineering: the question of justice"* | 2011 | - Argues that SAI has shortcomings in distributive, intergenerational and procedural justice.<br>- Unilateral SAI deployment goes against principles of procedural justice. |
| **Breena Holland** | *"Procedural justice in local climate adaptation: political capabilities and transformation change"* | 2017 | - Procedural justice ensures vulnerable populations' political control over their environment.<br>- Not following procedural justice might reproduce inequities. |
| **Marion Hourdequin** | *"Climate change, climate engineering and the 'Global Poor': what does justice require"* | 2018 | - Critique of the argument that solar geoengineering would in the best interest of the global poor.<br>- Geoengineering requires a multidimensional approach of justice. |
| **Marion Hourdequin** | *"Geoengineering justice: the role of recognition"* | 2018 | - Solar geoengineering might exacerbate climate injustices.<br>- Include diverse perspectives is essential.<br>- Recognition provides a normative framework to ensure justice in the field. |
| **Clare Heyward** | *"Normative issues of geoengineering technologies"* | 2018 | - Procedural justice is about fairness of decision-making procedures.<br>- Technological innovations, like solar geoengineering, might disregard procedural justice. |

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| **Duncan P. McLaren** | *"Whose climate and whose ethics? Conceptions of justice in solar geoengineering modelling"* | 2018 | - Model assumptions disregard important justice consideration, thus reproducing power asymmetries.<br>- Climate models should improve to include justice concerns. |
| **Brandstedt & Brülde** | *"Towards a theory of pure procedural climate justice"* | 2019 | - Distribution of benefits is unfair.<br>- Procedural justice norms, like transparency, reciprocity and participation would make negotiations fair.<br>- Following these norms creates trust, predictability and accountability. |
| **Daniel, Edward & Callies** | *"Institutional legitimacy and geoengineering governance"* | 2019 | - Procedural justice in geoengineering governance means ensuring fair terms of inclusion and participation.<br>- Not including directly affected voices would be procedurally unjust. |
| **Augustine Pamplany** | *"The ethical desirability of geoengineering: challenges to justice"* | 2020 | - Solar geoengineering poses serious ethical and justice challenges.<br>- A primary concern of procedural justice is the participation and involvement of vulnerable people and indigenous people in decision-making processes. |
| **Sovacool, Baum & Low** | *"Climate protection or privilege? A whole systems justice milieu of twenty negative emissions and solar geoengineering technologies"* | 2022 | - Solar geoengineering technologies rise participation concerns, particularly regarding who gets to be heard in the processes. |

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| **Mettiäinen et al.** | *"Bog here, marshland there: tensions in coproducing scientific knowledge on solar geoengineering in the Arctic"* | 2022 | - Viewpoints of Arctic communities are highly overlooked in the scholarship of solar geoengineering.<br>- Stress the need for co-production of research. |
| **Marco Grasso** | *"Legitimacy and procedural justice: how might stratospheric aerosol injection function in the public interest?"* | 2022 | - Inclusion and legitimacy are essential justice elements to ensure SAI is performed and research in the public's interest. |
| **De Ridder et al.** | *"Procedural climate justice: conceptualizing a polycentric solution to a global problem"* | 2023 | - Procedural justice in climate governance can enhance properties of polycentric systems.<br>- Procedural justice is best observed in polycentric systems, which are responsive of innovations and can best cope with uncertain futures. |