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Geoengineering research and governance:
trade-offs, justice, and mental health in the Global South

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Final Report

The health implications of SRM ethics and governance: a Global South perspective

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Executive summary

As the global failure to curb emissions continues, the world faces a worsening climate-health crisis. Solar Radiation Modification (SRM) is increasingly discussed as a potential intervention to alleviate climate impacts, but presents deep uncertainties, known and unknown risks as well as complex scientific, ethical, social, and public health trade-offs.

This Report has been undertaken at the *Bioethics Program, FLACSO Argentina* in collaboration with international researchers. This three part-Report aims to provide a clear overview of the current ethical debates surrounding governance and public engagement of SRM and possible health consequences. It also attempts to sketch some answers and to provide a roadmap for the World Health Organization (WHO) to ask questions about the health-related ethics and governance of SRM. And hopes to show that—though SRM is in a preliminary stage and it is not certain it will be deployed—an anticipatory governance framework is urgently needed. And that WHO may be one among the international organisms to take the lead.

Part I situates SRM governance within the broader climate response action portfolio and underscores some of its challenges and gaps in governance. We then focus on the analysis of relevant terminology, particularly the idea of defining SRM and geoengineering in terms of their aims. We build on this analysis to address basic aspects of ethics and governance of SRM research.

Part II undertakes a bibliographic review of the current literature of SRM and human health. The literature on human health consequences of SRM is limited, and there is a growing agreement that SRM would generate uneven human-health outcomes across regions due to higher exposure to vulnerabilities that amplify cascading health risks in the Global South. We also consider mental health within a public health framework, and argue that any SRM scenario should be accompanied by investment that aims to promote and safeguard public mental health. This Part highlights the importance of investigating the physical and mental health consequences of SRM in order to avoid exacerbating existing health risks and vulnerabilities.

Part III moves to the global arena and its governance challenges. We first review the main ethical and governance frameworks proposed to guide research and potential deployment of SRM, with a focus on their relevance to human health. We find scarce representation of the Global South in the development of these proposals and mostly indirect references of the impacts of these technologies on human health. We then focus on public engagement through a health lens, and argue from a perspective of global climate justice that governments and international organisations should invest in and strengthen capacity-building initiatives to ensure meaningful participation of researchers and local communities. Finally, we propose some considerations for an anticipatory governance framework to align current considerations on SRM with the health protection mandate and policy frameworks of the WHO and its Member States.

We propose several ethical considerations :

1) to prioritize mitigation and adaptation as climate response options, and mandate non-substitution as an enforceable guardrail;
2) to anchor all SRM governance of WHO in a “health-first” mandate;
3) to encourage research and knowledge on health impacts within SRM balance assessments;

4) to design an international anticipatory system of good governance;
5) to center equity, justice and co-stewardship by the Global South and communities with vulnerabilities, and
6) to consider the interests, voices and specificities of the different countries and regions of the Global South.

Introduction[1]

Solar Radiation Modification (SRM) refers to experimental interventions such as "stratospheric aerosol injection" (SAI) which draw on proposed planetary scale techniques that typically reduce absorbed solar energy or enhance emissivity of outgoing trapped radiation[2]. Those interventions might not sound like a central concern for either the WHO, nor for the field of bioethics, especially given the expert consensus that SRM interventions are no substitute for mitigation or adaptation, but a potential third type of action within the climate response portfolio (COMEST, 2023).

Nevertheless, this three part-Report draws on an interdisciplinary approach to tackle issues at the intersection of climate, environment and health to enable a more adequate understanding of the diverse dimensions involved. It aims to provide conceptual clarity in its overview of the current debates surrounding ethics, governance, and public engagement in any scenario of SRM research or deployment. It also attempts to sketch some answers and to provide a roadmap for the WHO to ask questions about the health-related ethics and governance of SRM.

A major challenge we faced was the scarce attention to the intersection of SRM and health within both the scientific and ethical literature. SRM is often framed as an engineering proposal to alleviate the suffering caused by climate change, and as a matter of security and foreign policy, but rarely as an issue of health. We recognise that we are treading relatively new ground, but it is our hope that this Report will contribute to a "health framing" of SRM research and its potential deployment. Thus we argue that health impacts could be useful to ground questions of governance.

The WHO definition of health as 'a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity' is socio-political and attempts to provide grounds for achieving health equity (Valles, 2018). Health has been generally under-theorised from an equity perspective within philosophical schools of thought (Venkataparum, 2011). We briefly underscore the fruitfulness of thinking about health from the point of view as a capability for three reasons. First, because it stresses the difference between the possibility of maximal physical and mental health (as per the WHO definition) and the actual realisation of them. Second, by evaluating a person's well-being based on objective abilities to achieve a life they value, instead of their resources or subjective feelings, it demands that policy makers look beyond concerns with material deprivations to include social and political deprivations such as oppression and discrimination. This also includes a focus on climate justice (Robeyns & Byskov, 2025). Third, the capabilities approach allows us to approach the question of the Global South.

Early definitions of the Global North and South focused on economic dominance and dependency, were based on regions, or provided a more metaphorical approach to oppression. From the perspective of public health, we can define the Global South as those situations in which the majority of people are more exposed, relative to the North, to many different "layers of vulnerability" (Luna, 2019), whether they be socioeconomic, judicial, or other. This is true across the board, but the Global South also includes very different regions, each of them with different

[1] Main contributors: Florencia Luna and Timothy Daly.

[2] Solar radiation modification. "Refers to a range of radiation modification measures not related to greenhouse gas (GHG) mitigation that seek to limit global warming. Most methods involve reducing the amount of incoming solar radiation reaching the surface, but others also act on the longwave radiation budget [outgoing trapped radiation] by reducing optical thickness and cloud lifetime". (IPCC [AR6, Glossary] 2021, edited).

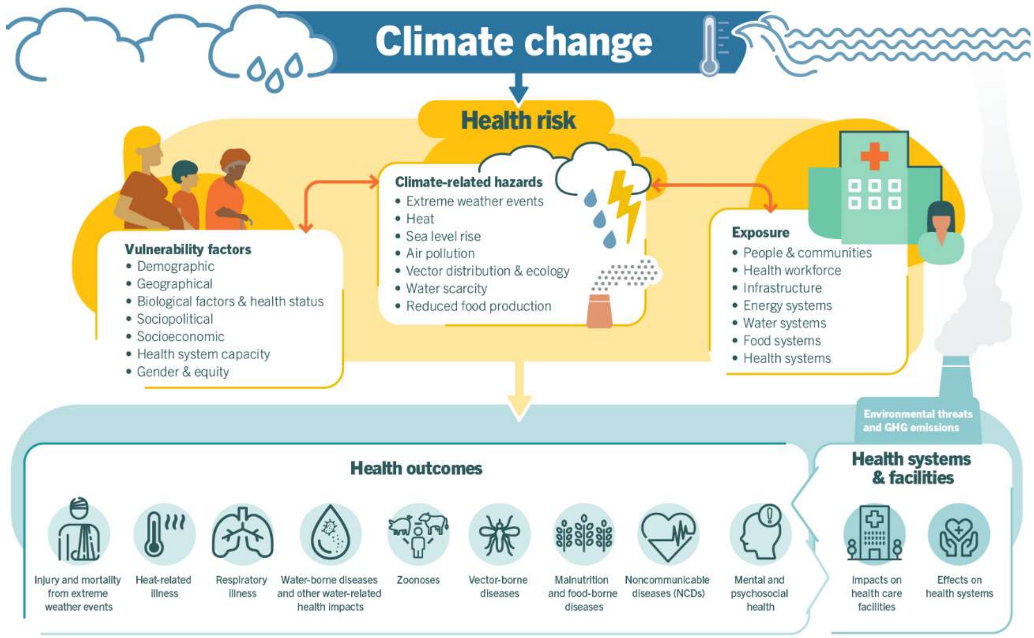
challenges and particularities in relation to climate change, SRM, diseases and health systems.

Because of the overlapping nature of layers of vulnerability (Luna, 2019), climate change has multiple cascading health impacts across regions like Latin America and the Caribbean (Hartinger et al., 2025). For example, during 2023–2024, Brazil and other Amazonian countries were affected by the combination of prolonged drought, intense heatwaves, and wildfires, driven by climate change, deforestation, and El Niño. Widespread drought was observed in the Amazon and Pantanal in 2023–2024, with rainfall 30%–40% below normal and the Rio Negro in Manaus reaching a record low. Between August and December 2023, Brazil and other South American countries reported record maximum temperatures and multiple heatwave episodes, aggravated by El Niño, which worsened the Amazonian drought. Parallel to the droughts, Brazil suffered intense rainfall events and subsequent flooding. Simultaneously, the drought and extreme heatwaves led to unprecedented wildfires in the Amazon and Pantanal regions in 2024, leading to important consequences to health due to $PM_{2.5}$ smoke exposure. The increase in mean temperature is also related to a major increase of dengue cases in Brazil (see Panel 2, p. 7, Hartinger et al., 2025).

These Amazonian impacts of climate change represent an entirely different situation to the one that small islands in the Caribbean face, particularly the question of how rising sea levels may force extensive migration (Lacarte et al., 2023), with major impacts on mental health. By zooming in on the problems facing Latin America and the Caribbean alone, we can see that it is thus unlikely to be useful to use the Global South as a blanket term, but instead, to use it as a starting point to investigate vulnerabilities affecting the majority of people's health. Countries and world regions generally considered to be within the Global South face very different problems: Pakistan faces extreme weather events and sea level rises, South Africa faces droughts and loss of tourism, Malaysia faces extensive damage to its rainforests and marine ecosystems (Romanello et al., 2025).

Pre-existing vulnerabilities allow us to understand how climate change is the greatest threat to physical and mental health equity (Sheather et al., 2023; see Figure 1).

Figure 1. — Climate change impact on health outcomes framed in terms of their vulnerability factors, hazards, and exposure.



Source: World Health Organization (2021c, p. 13).

An argument for the WHO engaging with SRM ethics and governance can be formalized as follows:

1) Climate change is the largest known threat to global health equity.
2) Given that mitigation and adaptation may not be sufficient.
3) SRM has the possibility of reducing temperatures and thereby health impacts, while introducing some known and unknown new risks.[3]
4) There is a risk that market-based SRM governance will prevail without the governance efforts of countries and international organizations like the WHO.

To make this point more concrete, consider the following example from the Latin American and Caribbean region from whence this report originates. Message three of the October 2025 Lancet Countdown Latin America mentions effective governance, “defined by action, accountability, and measurable health impacts” (Hartinger et al., 2025, p. 5) as necessary to address the escalating health impacts of climate change. The report makes no mention of SRM, which is absent from Latin America’s climate portfolio. But there have been some regional SRM non-research experiments without specific governance[4]. Our group has underscored and written about the small-scale deployment of sulfur dioxide-containing balloons released by the US Startup “Make Sunsets” in April 2023 in Baja California, Mexico, without appropriate public and expert engagement (Carabajal et al., 2025). This led the Mexican government to announce its intention to ban both research and non-research geoengineering experiments[5]. The Mexico case demonstrates that for-profit companies monopolizing SRM would make effective governance almost impossible (Surprise et al., 2025) and that denying the possibility of SRM can be counterproductive and even riskier than facing the problem and establishing a governance structure.

[3] As we will see through this Report there are still many unknowns with regards to the empirical reality of whether SRM would achieve equitable protection of public physical and mental health.

[4] For an in depth analysis of the concept of SRM experiment and the distinction between SRM research and non-research experiments see Annex 1.

[5] For an analysis of the relation between the activities of geoengineering and SRM see Chapter 2.

In addition to for profit companies' actions, there is the challenge of global governance and the possibility of enforcement on a technology that proves to be quite controversial. SRM is one of many policy domains where all options create some net losers, including from a health perspective, making trade-offs unavoidable (see Postface). Furthermore, we have recently witnessed with the COVID 19 pandemic how, even when there were strong data for the need of cooperation and actions based on solidarity, this was not achieved. And, for example, an international mechanism such as COVAX was boycotted (Luna, forthcoming), leaving the world in a Hobbesian state of nature ("war of all against all") with the best resourced countries hoarding unnecessary amounts of vaccines and leaving needful countries in a state of deprivation. SRM presents arguably even more difficult challenges and dangers than the COVID pandemic. Its global governance is another major challenge. And as it will be pointed out in chapter 2 (section 2.3), the debate around SRM possible acceptance and deployment is marked by disagreement (Biermann et al., 2022; Parson et al., 2024). Thus, it needs an adjusted, timely and global governance system. To achieve this, we need anticipatory thinking on possible answers. This Report exhibits different challenges and problems and proposes possible answers that an international organism in public health may begin to consider.

This report has three parts. Part I includes two chapters that introduce the themes of the report and define SRM and the gaps facing ethics and governance. The first chapter situates SRM governance within the broader climate response action portfolio and ends underscoring some of the challenges and gaps in governance as well as enumerating some relevant consensus documents from the science-policy literature. The second chapter is devoted to defining what SRM is in ways that are amenable to ethical analysis. The key element is defining activities based on their primary aims. Aims-based definitions are thus useful for a case-by-case approach to SRM research ethics and governance. As we will see in different examples throughout this report, understanding the intended aim of different activities relevant to geoengineering helps a governance regime in "determining whether expected benefits exceed expected damage in any particular case" (Ricke, Moreno-Cruz & Caldeira, 2013). This chapter ends with the presentation of the main ethical values for ethics and governance.

Part II focuses more specifically on health and it presents known empirical facts. It also has two chapters. Chapter 3 starts by presenting a bibliographic review of the current literature on the intersection between SRM and human health. Key findings are, first the scarcity of studies on SRM and health. Second, the growing agreement that SRM would generate uneven human-health outcomes across regions, with these disparities becoming especially complex in the Global South because of overlapping vulnerabilities that amplify cascading health risks. Third, the review also identifies a significant knowledge gap in Latin America and the Caribbean. Chapter 4 examines the implications of SRM research and deployment within a public mental health framework. It ends by outlining that investment in technical capacity for SRM should be accompanied by investment in co-interventions that aim to promote and safeguard public mental health.

Finally, Part III discusses what SRM governance for a healthy future could look like. The first chapter of this part (Chapter 5) reviews the principal ethical and governance frameworks proposed to guide research and potential deployment of SRM, with a focus on their relevance to human health. We can draw two main conclusions from our analysis: first, most of the documents considering governance of SRM only consider health in an indirect way. Second, the scope of the proposals of the majority of the ethical and governance documents is domestic, they are informal (not binding), and have an over representation of Global North perspectives (Brent et al., 2024). This means that, even if we know that the impact of possible deployments of these technologies is global (and will have an uneven impact in different countries and regions), up to now, there has been very little consideration of governance of these technologies within a global vision.

A further issue was the repeated importance of doing public engagement in order to build trust and transparency. Thus, Chapter 6 analyzes how to undertake a meaningful public engagement process with a contested, global technology. For example, it implies rethinking the science-public relationship in order to see how to best ensure respectful participation. Besides exploring some of the methodological challenges of this fundamental process, we outline the key function that introducing the health impact in participatory debates may play. Even though health is an end in itself, as per the WHO founding mission of health for all, health impacts could also be used as a means to engage the public and bridge the gap this complex and controversial technology entails.

Finally, Chapter 7 shifts to the global arena and governance challenges. It is an exploratory chapter that attempts to imagine how the WHO can engage with SRM given its commitment to global public health. It proposes some considerations for an anticipatory governance framework to align current considerations on SRM with the health protection mandate and policy frameworks of the World Health Organization (WHO) and its Member States. It provides policy options, guardrails, and measurable indicators to equip the health community to lead these deliberations from a "health-first" and "do-no-harm" perspective in the form of considerations, access points for WHO action, and the rationale for principles and guidelines.

The main conclusions of this third part highlight the importance of incorporating systematic evaluations of health-related risks into future governance frameworks, to ensure public engagement and to safeguard physical, mental and ecosystem health, with an emphasis on more vulnerable countries and regions, in any possible scenario of SRM.

This report is not prescriptive on what the WHO's role on SRM governance should be. The aim is to clarify the existing science-policy literature so as to equip the WHO on how to deliberate across the full spectrum of research and deployment options, guided by "a truly integrated perspective and coordinated action, based on a whole-of-government, whole-of-society and the One Health approach" (WHO, 2024, p. 3). It also aims to show that though SRM is in a preliminary stage and it is not certain whether it will be deployed, an anticipatory governance framework is urgently needed. The WHO could be one of the main international organisms to take the lead.

Part I. Understanding SRM: fundamental concepts and ethics

Chapter 1. SRM within the climate response portfolio[6]

Solar geoengineering (SG) or solar radiation modification (SRM) are both umbrella terms with similar scope that typically refer to experimental technologies that could be used to significantly modify incoming solar radiation or outgoing trapped radiation (see Chapter 2 for a terminological analysis of SRM). SRM introduces an activity distinct from conventional climate action strategies, such as mitigation (i.e. cutting emissions), adaptation or carbon dioxide removal (CDR) (COMEST, 2023)[7]. Given the likelihood of exceeding the Paris Agreement target of keeping the global temperature rise above 1.5º C during this century (Diffenbaugh & Barnes, 2023), coupled with the continued increase in greenhouse gas emissions, climate change is arguably one of the most pressing crises in modern history. In this context, SRM is being given significant consideration as a means of mitigating the catastrophic impact on populations, particularly with regard to population health.

One of the most researched technologies of SRM is Stratospheric Aerosol Injection (SAI), whereby sulphur dioxide (SO_2) particles are deployed into the stratosphere to reflect sunlight back into space and cool the planet (Camilloni et al., 2022). This approach would mimic the effect of a volcano eruption, such as Mount Pinatubo in 1991, when, according to the US Geological Survey, the spread of tons of SO_2 cooled the Earth, temporarily dropping the temperature by 0.5º C between 1991 and 1993 (Soden et al., 2002). One key feature of SAI is that it would be relatively inexpensive to develop (Smith, 2020) and might produce rapid results, if data from natural analogues are indeed relevant predictors. Therefore, it is expected to be highly feasible and effective. For this reason, as we will see in the next sections, it is a relatively rapid and temporary technology that can offset the impacts of climate change (see Table 1 below).

Nevertheless, SRM does not address the root physical causes of climate change: it does not reduce greenhouse gases emissions—it masks the warming it generates. And while it could bring potential benefits, it also poses potential unknown risks[8] and uncertainties to humans and ecosystems (IPCC, 2023). Moreover, the distribution of risks will not be equal, just as the risks of climate change are unequal. The risks posed by deployment of these technologies to human health are unknown. Another risk of these SRM technologies is that they could be used unilaterally, or even

[6] This introduction and section 1-6 are partly based, revised and edited of an article recently published by key members of the WHO research team (Carabajal et al., 2025); and has contributions from Ignacio Mastroleo and Timothy Daly (section 1.4-1.5), Hassaan Sipra and Shuchi Talati (section 1.1-1.3; 1-7).

[7] The term mitigation here and in the literature is sometimes used with a narrower scope than in the IPCC AR6 which includes cutting or reducing emission and technologies to enhance carbon sinks, including CDR. For critical comments on this IPCC definition of mitigation see COMEST (2023). Readers should be aware from the context whether mitigation includes or not enhancing carbon sinks.

[8] In this Report we adopt the definition of risk as presented by Felgenhauer et al. (2024) following the US Department of Homeland Security: "the potential for an unwanted outcome resulting from an incident, event or occurrence, as determined by its likelihood and the associated consequence" (US Department of Homeland Security, 2010). This broad definition acknowledges that risks are diverse in magnitude, scale, type and distribution. Any climate intervention could trigger different types of risks (Davies & Vinders, 2025; Santi, 2015), which refers not only to health risks but also environmental, political and ethical concerns that could exacerbate global conflicts.

weaponised, by ‘rogue’ actors

This chapter situates SRM governance within a broader climate response action portfolio, underscores gaps in governance, and lists relevant consensus documents.

1.1. Comparing different strategies against climate change

The two consensus types of action in the global climate portfolio are mitigation[9], and adaptation[10]. Mitigation and adaptation require decades of investments and commitments from governments, businesses, and civil society actors across the world to keep the global temperature within “safer” operating limits as outlined by the Paris Agreement (2015) that governments collectively agreed is acceptable: “pursuing efforts” to keep global average temperature under 1.5°C, and “well below” 2°C, as compared to a preindustrial era, circa 1850 (Paris Agreement, 2015, Article 2). The IPCC now considers that carbon dioxide removal (CDR) is necessary to achieve the 1.5°C limit, and that temperature overshoot[11] is highly probable. Thus, in addition to mitigation and adaptation, scientific and policy debates have added CDR, which is implicitly included in the definition of mitigation in IPCC AR6 under the label of “enhance the sinks of greenhouse gases” (COMEST, 2023)[12].

In response, a further strategy is also being intensely scrutinized to help return the global temperature toward those limits: solar radiation modification (SRM). This strategy is currently theoretical, but the engineering knowledge to make it happen is present or achievable, in the very near-term (UNEP, 2023b). Table 1 describes the main differences between these strategies (mitigation, adaptation, CDR and SRM) regarding: health benefits, risk involved, equity implications and governance.

[9] Mitigation. “A human intervention to reduce emissions or enhance the sinks of greenhouse gases.” (IPCC [AR6 Glossary] 2021).

[10] Adaptation. “The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.” (IPCC [AR6, Glossary] 2021, edited).

[11] This definition is based on the latest Intergovernmental Panel on Climate Change (IPCC), the highest scientific body on the subject Sixth Assessment Report AR6.

[12] Carbon dioxide removal (CDR). “Anthropogenic activities removing carbon dioxide (CO2) from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products” (IPCC [AR6, Glossary] 2021, edited). Previous versions of the AR6 IPCC glossary include CDR and SRM under the label of geoengineering (e.g. IPCC 2012:2, 2019). See Chapter 2 for a detailed analysis.

Table 1. Comparative overview of mitigation, adaptation, CDR and SRM

Strategy	Time to health benefit	Risk profile (technical/systemic)	Equity implications	Governance maturity
Mitigation	Near-term (months–years) via air-quality and co-benefits; long-term via reduced climate risk[13].	Well-characterized technologies; system-transition risks (stranded assets, just transition) but manageable with policy[14].	Strong positive distributional effects if targeted; benefits greatest for high-pollution and vulnerable populations[15].	High: extensive multilateral architecture under UNFCCC[16]/Paris; national policies and standards[17].
Adaptation	Immediate to medium-term through reduced exposure and strengthened health systems[18].	Context-dependent; risk of maladaptation if poorly designed[19].	Can reduce inequities when inclusive; risks exacerbating inequities if access is uneven[20].	Moderate: expanding guidance and finance under UNFCCC; variable national capacity[21].
CDR	Medium- to long-term; depends on scale and pathway; potential near-term air-quality trade-offs for some option[22].	Technical feasibility and sustainability constraints at scale; land/water/energy trade-offs[23].	Land and resource footprints raise justice concerns; requires safeguards and participation[24].	Low–moderate: emerging standards; no dedicated global framework; reporting intersects with UNFCCC inventories.
SRM	Potentially rapid climate-risk reduction if effective, but no health benefits guaranteed	High uncertainty and systemic risk; risk of termination shock; cross-border externalities[25].	Distributionally uneven impacts possible; risk of burden-shifting; legitimacy requires inclusive governance[26].	Low: no Deployment-ready governance[27]. EU Scientific Advisors advocate moratorium while pursuing research governance[28].

[13] WHO (2021c, pp. 9-11); IPCC (2023, p. 13).
[14] IPCC (2023, p. 13, pp. 24–25).
[15] WHO (2021c, pp. 9–11).
[16] United Nations Framework Convention on Climate Change (UNFCC) / Paris Agreement (2015).
[17] UNFCC / Paris Agreement (2015, p. 3; Art. 2).
[18] WHO, (2021c, p. 10); IPCC WGII SPM (2022, pp. 27–31).
[19] IPCC WGII SPM (2022, p. 30).
[20] IPCC WGII SPM (2022, p. 30).
[21] IPCC WGII SPM (2022, pp. 27–31).
[22] IPCC WGIII (2022, p. 1); IPCC (2023, p. 28).
[23] IPCC (2023, p. 28).
[24] IPCC, (2023, p. 28).
[25] SAPEA, (2024, pp. 10–12); OSTP, (2023, pp. 8–9).
[26] NASEM (2021, Summary, pp. 5–7); IPCC WGII SPM (2022, p. 30).
[27] CBD (2010) decisions X/33 & CBD (2012) XI/20 caution.
[28] CBD (2010, pp. 4-8(w)); CBD (2012, p. 1); GCSA (2024, pp. 4–5).

Although discussions concerning these strategies including its risks, benefits and governance challenges are growing, especially in academia, SRM remains an unfamiliar topic in the political and social domains (Baum et al., 2024).

1.2. Why mitigation and adaptation remain first-order priorities

The IPCC stresses that limiting climate change risk requires deep, rapid, and sustained emissions cuts across all sectors this decade (IPCC, 2023, p. 25). Each additional increment of warming intensifies concurrent hazards (IPCC, 2023, p. 17). Options for adaptation become more constrained beyond 1.5 °C (IPCC, 2023, p. 24), and specifically have "soft" and "hard" limits defined by the IPCC, several of which have already been crossed (IPCC, 2023, p. 57). The World Meteorological Organization now considers an ~80% probability that at least one year between 2025–2029 exceeds 1.5°C, and a ~47% chance that the five-year mean hits 1.5°C (WMO, 2025, p. 1). The climate portfolio priority should reiterate the need to accelerate mitigation and invest in robust and equitable adaptation for health systems.

From a health perspective, mitigation delivers immediate co-benefits. To name a few, these include cleaner air, safer transport, and healthier diets (for example, through reduced consumption of red meat). The World Health Organization's (WHO) climate-and-health guidance emphasizes prioritizing climate interventions with the largest health, social, and economic gains (notably phasing out coal, expanding active mobility, and improving food systems), can yield substantial near-term public-health benefits (WHO, 2021c, p. 9–11). The conclusion is that the public health benefits of ambitious climate action outweigh their costs (WHO, 2021c, p. 60). The IPCC likewise highlights health co-benefits from reduced air pollution and enhanced energy security when mitigation is pursued at scale (IPCC, 2023, p. 13). Health-centred adaptation includes the following actions, which are prioritized in the WHO recommendations (WHO, 2021, p. 10): climate-resilient health services, early-warning systems, climate-informed surveillance, water, sanitation, and food security measures.

1.3. Completing the portfolio: CDR and SRM (distinct roles, different risk profiles)

CDR's role is complementary. IPCC clarifies that CDR can counterbalance residual emissions where full decarbonization is not yet feasible, but is not a substitute for deep emissions reductions (IPCC & WGIII, 2022, p. 1), while recognizing that CDR also requires significant resources to operate at scales not yet achieved. In scenarios where temperatures overshoot 1.5°C, returning below that level depends on sustained net-negative greenhouse gas (GHG) emissions and greater CDR deployment. This raises major concerns around the feasibility and sustainability of such a scenario (IPCC, 2023, p. 28).

SRM's role is fundamentally different. The science-policy literature emphasizes that while SRM could reduce some warming and associated risks, benefits and risks remain highly uncertain, unevenly distributed, and thus, SRM is not ready for deployment (SAPEA, 2024, p. 10–12). Leading public bodies converge on the need for all SRM-related research to be conducted under rigorous governance that centers transparency, public engagement (especially with Global South stakeholders), risk management, and international cooperation (OSTP, 2023, p. 4, p. 7–9; SAPEA, 2024, p. 169–172). We will expand on these issues in the next chapters. The IPCC 2023 synthesis report on SRM techniques stresses that:

> "[I]f they were to be implemented, they introduce a widespread range of new risks to people and ecosystems, which are not well understood. SRM has the potential to offset warming within one or two decades and ameliorate some climate hazards but would not restore climate to a previous state, and substantial residual or overcompensating climate change would occur at regional and seasonal scales (*high confidence*). Effects of SRM would depend on the specific approach used, and a sudden and sustained termination of SRM in a high CO2 emissions scenario would cause rapid climate change (*high confidence*). SRM would not stop atmospheric CO2 concentrations from increasing nor reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). Large uncertainties and knowledge gaps are associated with the potential of SRM approaches to reduce climate change risks" (IPCC, 2023, p. 72).

Thus, discussions about SRM are characterised by intense disagreements about the feasibility and desirability of its deployment (Scientific Advice Mechanism to the European Commission, 2024). A health-centered framing of governance suggests that research on SRM should be guided by the aims of reducing human suffering and avoiding harm to ecosystems (WHO, 2021c, p. 9–11; SAPEA, 2024, p. 10–12; IPCC, 2023, p. 17).

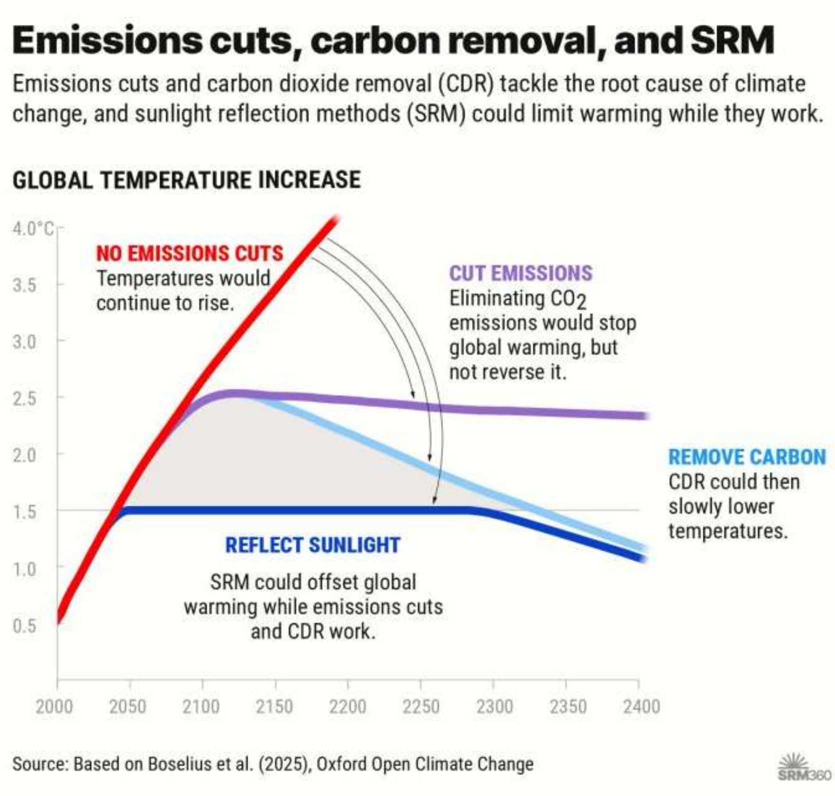
1.4 The napkin diagram: visualizing SRM within the climate portfolio

Now, we believe it would be useful to visualize the above points made about SRM and the impacts of its deployment. If the discussion of SRM were to be summarized in one image (which itself comes with trade-offs), that image would be Shepherd's napkin diagram (see Figure 2)[29]. The napkin diagram "describes [...] the role of SRM as part of a multi-faceted response to climate change" (SRM Primer, 2024). In other terms, it presents graphically the role of SRM as a new potential addition to the portfolio of actions to respond to climate change threats and negative impacts, complementary to CDR, mitigation and adaptation as defended by the Royal Society (Shepherd & WGGC, p. 2009).

This idea of a portfolio or deliberate selection of multiple actions with different mechanisms, timings, risk-benefit profiles, etc. is widely present in the literature of climate studies (e.g. Keith, 2013; IPCC, 2014; Jamieson, 2014; COMEST, 2023) but we could not identify a single origin. It is also the representation of one of many exemplary scenarios of deployment strategy known as "peak shaving" scenario, where SRM is used as means to shave the peak of overshooting, but there are other potential scenarios for SRM use (UNEP, 2023b, p. 10; Royal Society, 2025, p. 20, figure 3).

[29] According to SRM Primer "There are many variations on this sketch, which is often referred to as the "napkin diagram" (as it was originally sketched on a napkin by J. Shepherd in 2009" (SRM Primer, 2024). Shepherd was the lead author of the Royal Society's report (Shepherd & WGGC 2009).

Figure 2. Napkin diagram



Source: SRM360 (2025), based on Boselius et al., (2025).

The napkin diagram captures in a single graph the limited and temporary role or function, if ever, of SRM as a potential tool within the portfolio of actions to respond to negative outcomes of climate change. The red curve represents the "not cutting emissions" scenario, where temperature and negative impacts continue to rise. The three other curves, show the portfolio or deliberate combination of reducing or cutting emissions (first part of the IPPC AR definition of mitigation) and removing carbon (CDR) that aims at the root physical causes of warming that works in a larger time scale while SRM kicks in to potentially complement the other two in a shorter term "while emissions cut and CDR work".

The napkin graphic also represents the general assumption of the defenders of SRM research, that cutting emissions and CDR may not be enough, only by themselves, to keep warming within the 1.5-2° harm threshold. The napkin diagram only captures the risks and negative impacts eliminated by the portfolio or "multi-faceted response" (SRM Primer, 2024) to climate change, including SRM vs. not including SRM. It does not show the risk created by including SRM in the portfolio of responses. Hence, the napkin diagram fails to show the risk-risk tradeoffs of risks eliminated and the risks created by the portfolio response, and particularly of SRM (Felgenhauer et al., 2025). A risk-risk comparison or balance assessment of SRM at international forums has been proven to be challenging (Royal Society, 2025, p. 99).

1.5. Risks of incorporating SRM within the climate response portfolio

We present two key arguments of risks associated with SRM: termination effect and mitigation deterrence.

1.5.1. Termination effect

Given the nature of SRM climate interventions such as SAI or SRM, they introduce a new risk of termination effect if they were to be used as part of the portfolio of responses to climate change impacts. Also known as "termination shock" and "effects of cessation of SRM". As the Royal Society explains about aerosol based SRM climate interventions:

> "Aerosols that cause SRM's cooling effect are much shorter-lived in the atmosphere than gases most responsible for global warming. Hence, regular injections would be necessary to maintain the cooling effect. Depending on the intended extent of masking, and the success or otherwise to mitigate the greenhouse gas emissions, this implies that a long-term commitment to SRM could be necessary. Should injections be abruptly halted or significantly reduced in extent (unless it was for a short period – a few months to a year), there would be a termination effect where the climate would return to its state without SRM in about a decade. If temperatures would have continued to rise significantly without SRM, this termination effect would have strong impacts on sensitive planetary systems that cannot adapt quickly, such as natural ecosystems" (Royal Society, 2025, p. 102).

This figures both as a reason against doing research on SRM or potential deployment, but also as a risk that has to be taken into account in the design of any portfolio of responses that might include SRM, with appropriate measures to mitigate that risk. However, "termination effect" is only one technical issue of a broader technical and ethical aspect of SRM, which might be captured by the concept of "appropriate timing" of use (not too early… not too late, or not at all) (Mastroleo & Holzer, 2020, pp. 342-343). In each stage of the life cycle, there are appropriate timing issues both from technical and socio political aspects. For example, using our proposal in three broad classic stages (Fotion, 2014) of (i) responsible action before SRM, (ii) responsible action during SRM, (iii) responsible action after SRM, we could map termination effect together with other technical risks of appropriate SRM timing such as not too rapid initiation and not too rapid cessation to harm health or planetary systems (see chapter 2 for the concept of life cycle of SRM interventions).

1.5.2. Mitigation deterrence

The Royal Society defines mitigation deterrence –also known as "moral hazard" or "risk compensation"- (Keith, 2013) as the risk of "research and development of SRM to undermine efforts to cut emissions" (Royal Society, 2025, p. 99). This figures both as a reason against doing research on SRM or potential deployment (Biermann et al., 2022), but also as a risk that has to be accounted for in the design of any portfolio of responses to climate change impacts (IPCC, 2021; Royal Society, 2025).

If SRM is understood as a new action within a portfolio of responses to climate change, how should it be articulated with respect to the other actions of the portfolio, e.g. cutting emissions and adaptation, but also, other interventions such as CDR? Based on typical human behavior (e.g. weakness of will), Keith recognizes that introducing SRM could increase risk exposure (e.g. less efforts in cutting emission) after immediate risks of climate collapse have been reduced due to

SRM's cooling effects[30].

Moreover, SRM is likely to be cheaper than mitigation (and adaptation). Thus, for policy makers, it may be a more convenient and economically preferable option, making it preferable to mitigation and adaptation measures (EGE, 2024).

These concerns could be unified under the label of behavioral risks, within SRM and between activities of the portfolio of responses to climate change. However, “moral hazard" and other irrational[31] non-deliberate behaviors does not include mal-intent, that could also lead to similar outcomes, but that would require a distinct analysis from an ethical and legal point of view with different degrees of blame and responsibility.

This unification of risks may improve its identification and suggest common ways of dealing with such risks but does not solve the problem of how severe and probable the risks are in the real world. It also makes the theoretical assumption that we can distinguish with sufficient certainty when we are accepting a harmful intervention or rejecting a beneficial intervention.

More research is required to design and create a deliberative social process such as a Committee on SRM risks that complies with fundamental substantive and procedural ethical values (EGE, 2024) (see section 2.5). Given the current deep uncertainties about SRM at all levels recognized by authoritative reports (e.g. UNEP, 2023b; EGE, 2024; Royal Society, 2025), appropriate measures of risk management of the most salient risks should be taken for both risks of accepting an overall harmful SRM intervention or rejecting an overall beneficial SRM intervention, including the work on identification of potential threats and vulnerabilities that makes these risks more probable[32].

1.6. Governance gaps and challenges in SRM

Currently, there is neither a comprehensive governance system nor a forum in which the

[30] However, this observation only analyzes typical human behavior in the void, without taking into account other incentives and barriers that affect cutting emissions (e.g. rate investment and development of alternative clean sources). More research is required to map this risk of SRM within a unifying larger framework of human behavior, for example the work of Douglas (2000) on risk of errors or inductive risks in science or of Elster (1984)'s bounded rationality account on how we do not follow our best reasonable deliberations because of the “weakness of will” (incontinence or akrasia). This usually explains irrational behavior such as addictions, and other failures in human behaviors to maintain a best course of action also may serve to unify explanations of other problems such as “lock-in” or “slippery slope” effects from SRM research stages to SRM non-research experimental deployment stages (e.g. EGE 2024). This is usually captured by the more legalistic term of negligence.

[31] The concept of “moral hazard” or “risk compensation” presupposes that the agent is not doing what s/he considers should be best from a rational point of view (e.g. “cutting emissions at the appropriate rate”) because there is some form of temporal safety net (e.g. “SRM”), but recognizing that doing that (“cutting emissions”) is what a rational being that cares about others without weakness of will would do. What we here call irrational behavior, Elster (1984) calls “bounded rationality” and Aristotle calls it incontinence (*akrasia*). This should be distinguished from the rational behavior of not cutting emissions because the agent benefits temporarily from SRM and does not care about the future consequences for others, including the environment and future generations, which is a case of plain wrongdoing or *mal-intent*.

[32] The distinction of accepting a harmful intervention or rejecting a beneficial intervention has been developed together with Guillermo Marin Penella, Timothy Daly and Ignacio Mastroleo inspired by the idea of inductive risk or risk of error in philosophy of science (Douglas, 2000).

issue of SRM can be adequately discussed (Reynolds, 2019). The international concern surrounding the lack of, or insufficient, governance structures is growing, as many key questions remain unanswered. For example, who will monitor and regulate the research, funding, potential testing, and eventual implementation of such technologies? Who will have the authority to deploy SRM technology on a planetary scale?

Governance can take different forms, depending on the actors involved (international; domestic; governmental, non-governmental, and/ or the private sector), the different stages of the research process -from indoor research to outdoor experimentation and potential deployment and the near and long-term outcomes expected (UNEP, 2023b). The observations of Jinnah et al. (2018) demonstrate that the distinction between SRM development stages could be considered artificial from an ethical point of view. For example, relevant reports highlight the need for responsible research and ethical guidelines on indoor research (AGU, 2024). It has been argued that small-scale outdoor research experiments could provide a more precise understanding of SRM and improve the models, for example by providing a more accurate picture of the behaviour of reflective particles in the stratosphere. Therefore, a significant challenge lies in defining where, when and in which circumstances scientists should be allowed to carry out these outdoor field trials and their scope and in building participatory mechanisms, as there could be resistance from governments and communities (Jinnah et al., 2024). The complexity of SRM raises technical, socio-political and ethical discussions about whether it should be funded, researched or even promoted (Biermann et al., 2022).

Some groups opposed to SRM claim that the topic has been forced upon Global South countries, distracting attention from decarbonisation (Chalmin, 2024). However, we consider that countries in situations of exacerbated vulnerability must be aware of the potential risks and benefits, having a central role in the discussions (Rahman et al., 2018). This would entail improving Global South capacities, gaining access to breakthrough information, and understanding the array of impacts of SRM in the regions. Additionally, as technology evolves and new actors emerge, unforeseen events unfold[33], making anticipatory and participatory governance essential for overseeing and facilitating responsible research and inclusive dialogue, particularly in the Global South (AGU, 2024).

1.7. Landscape of international consensus documents and their intersection with climate-health SRM governance

Despite the absence of a governance framework, there are several documents dealing with climate change and SRM:

***United Nations Framework Convention on Climate Change (UNFCCC)/ Paris Agreement*.** Sets the temperature and adaptation goals underpinning climate policy; its preamble underscores the right to health and equity (Paris Agreement, 2015, p. 3; Art. 2). While Paris does not establish

[33] For example the US startup Make Sunset we refer to in the Introduction.

SRM research governance, Paris processes (e.g., transparency, Nationally Determined Contributions) define the mitigation‑ and adaptation-first context in which any SRM discourse should occur.

***World Health Organization (WHO)*.** Leads on climate‑health guidance (e.g., prioritizing interventions with the largest health gains; strengthening climate‑resilient health systems) and can inform health impact assessment standards based on its leadership in the matter for any climate intervention, including SRM research, though it has no SRM mandate (WHO, 2021c, pp. 9–11).

***Convention on Biological Diversity (CBD)*.** Parties have urged caution on climate‑related geoengineering: Decision X/33 calls for no activities that may affect biodiversity absent adequate science and effective governance, with a narrow exception for small‑scale research in controlled settings; Decision XI/20 reaffirms X/33 and notes large knowledge and governance gaps (CBD, 2010, p. 4; CBD, 2012, pp. 1–2).

***World Meteorological Organization (WMO)*.** Provides authoritative climate monitoring and outlooks that contextualize near‑term risk, such as, high probability of 1.5°C temperature overshoot averaged for 2025-2029 (WMO, 2025, p. 1).

***United Nations Environment Programme (UNEP) and United Nations Environment Assembly (UNEA)*.** UNEP commissioned One Atmosphere (2023b), an expert panel review concluding that SRM is no substitute for mitigation, carries significant uncertainties and ethical issues, and warrants a robust, inclusive international scientific review process. But it also points out that "SRM is the only option that could cool the planet within years" (UNEP, 2023b, Key findings pp. 1, 5–6; Exec. Summ., p. 8). UNEP's foresight report Navigating New Horizons (UNEP & ICS, 2024) flags "Deployment of SRM" as a signal of change requiring monitoring within an agile governance approach (pp. 44, 66) (UNEP & ISC, 2024). UNEP has also convened dedicated dialogues: a Consultative Workshop and Science‑Policy Dialogue on SRM in May 2025, co‑facilitated with WMO/ISC/WCRP (UNEP, 2025a, web), and a Multistakeholder Workshop on SRM in September 2025, to broaden participation (UNEP, 2025b, web). At the intergovernmental level, UNEA‑6 in 2024 saw submission of a draft SRM resolution by Switzerland/Monaco, which was ultimately withdrawn (UNEP, 2024a, draft resolution; UNEP, 2024b, session portal). Earlier, at UNEA‑4 (2019), Switzerland tabled a draft resolution on geoengineering governance that was also withdrawn (IISD ENB, 2019, web).

***United Nations Human Rights Council (HRC)*.** The HRC Advisory Committee's 2023 report, *Impact of new technologies intended for climate protection on the enjoyment of human rights* (A/HRC/54/47), examined CDR and SRM through a human‑rights lens. It warns that these technologies can interfere with the enjoyment of rights—including the rights to life, health, food, water, culture and a healthy environment—absent robust governance, transparency, and participation. It stresses precaution, distributional justice, and the protection of Indigenous Peoples and other groups in any research or policy consideration. This reinforces that any SRM research governance should be explicitly human‑rights‑based, not only risk‑based, with remedies and accountability mechanisms (HRC Advisory Committee, 2023, pp. 12, 32, 66–71).

United Nations Educational, Scientific and Cultural Organization (UNESCO) - Commission on the Ethics of Scientific Knowledge and Technology (***COMEST)*.** UNESCO's COMEST issued its first report on the ethics of climate engineering[34] in 2023, which argues that climate interventions such as solar radiation modification (SRM), which have emerged over the last decade as a technically feasible climate intervention aiming to cool the planet, are a third kind of activity, separate from mitigation and adaptation (COMEST, 2023). It proposes ethical lenses (human–ecosystem interconnectedness, intergenerational justice, proportionality, distributive justice) and concrete recommendations for research governance, including strong public oversight, transparency, and international cooperation. COMEST highlights moral‑hazard and lock‑in concerns, situates SRM as ethically fraught, and underscores that it cannot substitute for mitigation and adaptation. These conclusions align with a health‑first, precautionary framing for any SRM research[35].

***Montreal Protocol / Kigali Amendment*.** Phases down HFCs (hydrofluorocarbons)—short‑lived climate pollutants with high Global Warming Potential—delivering climate and health co‑benefits; not a forum for SRM, but demonstrates rapid, health‑aligned treaty action on specific agents (UNEP, 2023b, p. 1).

1.8. Final considerations

In this chapter we have mapped some of the basic actions within the portfolio responses to climate change impacts and the gaps in governance. Overall, we identified SRM as a distinct experimental and technically feasible climate response action that is undergoing intense debate in academic and, increasingly, policy circles (e.g. EGE, 2024; Royal Society, 2025). SRM could be used to alleviate some risks associated with climate change, but would introduce new categories of risk.

[34] The term climate engineering in COMEST includes two main categories CDR & SRM and replaces the older term of geoengineering in previous authoritative reports (e.g. Shepherd & WGGC, 2009; IPCC, 2012, p.2; IPCC, 2019). However the scope of both terms is similar. For a more detailed analysis see Chapter 2.

[35] See COMEST (2023, pp. 12–13, 25, 28–29).

Chapter 2. Clarifying SRM-related concepts and ethical justification[36]

Introduction

National or international authorities in charge of ethics and governance of solar radiation modification (SRM) research need to identify their intended remit of responsibility, and know the scope of actions or interventions covered by an ethical framework or regulation. A responsible SRM research scheme would require effective communication with affected parties in democratic societies (EGE, 2024). This chapter adopts a terminological analysis methodology (Jamieson, 2014) to improve understanding, promote effective responsible action and guide policymakers in their decision pathways.

1. Solar radiation modification is geoengineering: the historical definitions of the Royal Society and the IPCC

In 2009, the concept of SRM was introduced as one of the two main categories of geoengineering by the Royal Society (Shepherd & WGGC, 2009)[37]. The two authoritative definitions of geoengineering selected here explicitly refer to deliberate interventions into complex physical systems, typically the Earth climate system (e.g., Shepherd & WGGC [Royal Society], 2009; IPCC 2012, p. 2, quoted in IPCC, 2019) (see Table 2). The concept of intervention, including technological interventions as used in this analysis, presupposes human agency, and the distinction between deliberate aims, foreseeable associated effects and inadvertent effects. These distinctions typically track different levels of responsibility (Jamieson, 1996; Jamieson, 2014).

Table 2. Comparison of the Royal Society (2009) and IPCC (2012) definitions of geoengineering amenable to an ethics and governance analysis[38].

Definitions	**Royal Society's 2009 principal definition of geoengineering** . "Geoengineering, or the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change, has been suggested as a new potential tool for addressing climate change. Efforts to address climate change have primarily focused on	**IPCC's 2012 definition of geoengineering.** "A broad set of methods and technologies [means] that aim to deliberately alter the climate system in order to alleviate the impacts of climate change. Most, but not all, methods seek to either (1) reduce the amount of absorbed solar energy in the climate system (solar radiation

[36] Main contributors: Timothy Daly & Ignacio Mastroleo. The current chapter is based on an extended version of Mastroleo (2025a, 2025b).

[37] Before Royal Society's use, Morton mentions Ken Caldeira as the intellectual author of "solar-radiation management" ambage to avoid using "geoengineering" for a title of a NASA conference. "The term stuck and, abbreviated by the initials SRM, it has become ubiquitous in the literature" (Morton, 2016).

[38] In our terminological analysis of SRM, we have had to reconstruct the main practical aim of SRM taking it from the IPCC pre-AR6 glossary definition of geoengineering (see Table 2) because the IPCC AR6 glossary only captures part of the reconstructed scope of incoming and outgoing radiation (see Table 3). Solar radiation modification "refers to a range of radiation modification measures not related to greenhouse gas (GHG) mitigation that seek to limit global warming. Most methods involve reducing the amount of incoming solar radiation reaching the surface, but others also act on the longwave radiation budget [outgoing trapped radiation] by reducing optical thickness and cloud lifetime". (IPCC [AR6, Glossary] 2021, edited).

	mitigation, the reduction of greenhouse gas emissions, and more recently on addressing the impacts of climate change—adaptation”[39]. **Royal Society’s 2009 auxiliary definition of geoengineering.** “Geoengineering proposals aim to intervene in the climate system by deliberately modifying the Earth’s energy balance to reduce increases of temperature and eventually stabilise temperature at a lower level than would otherwise be attained”[40].	management, or solar radiation modification, SRM) or (2) increase net carbon sinks from the atmosphere at a scale sufficiently large to alter climate (i.e., carbon dioxide removal, CDR). Scale and intent are of central importance. Two key characteristics of geoengineering methods of particular concern are that they use or affect the climate system (e.g., atmosphere, land, or ocean) globally or regionally and/or could have substantive unintended effects that cross national boundaries. Geoengineering is different from weather modification and ecological engineering, but the boundary can be unclear”[41].
Umbrella term and main categories	Geoengineering. CDR & SRM are the “main groups”[42] or categories united by the concept of energy balance.	Geoengineering. CDR & SRM are “most, but not all”[43] proposals. CDR & SRM are described separately.
Main reference and aim	Intentional action (not accidental, nor side effect, nor physical event) to counteract anthropogenic climate change	Intentional action (not accidental, nor side effect, nor physical event) to alleviate the impacts of climate change
Means of modification of Earth climate system	Methods to modify planetary environment (Earth’s energy balance, not weather nor use on other planets) on a large-scale	Methods and technologies to alter the climate system (not weather, nor use on other planets) on a scale large enough to alter the Earth’s climate system, globally or regionally

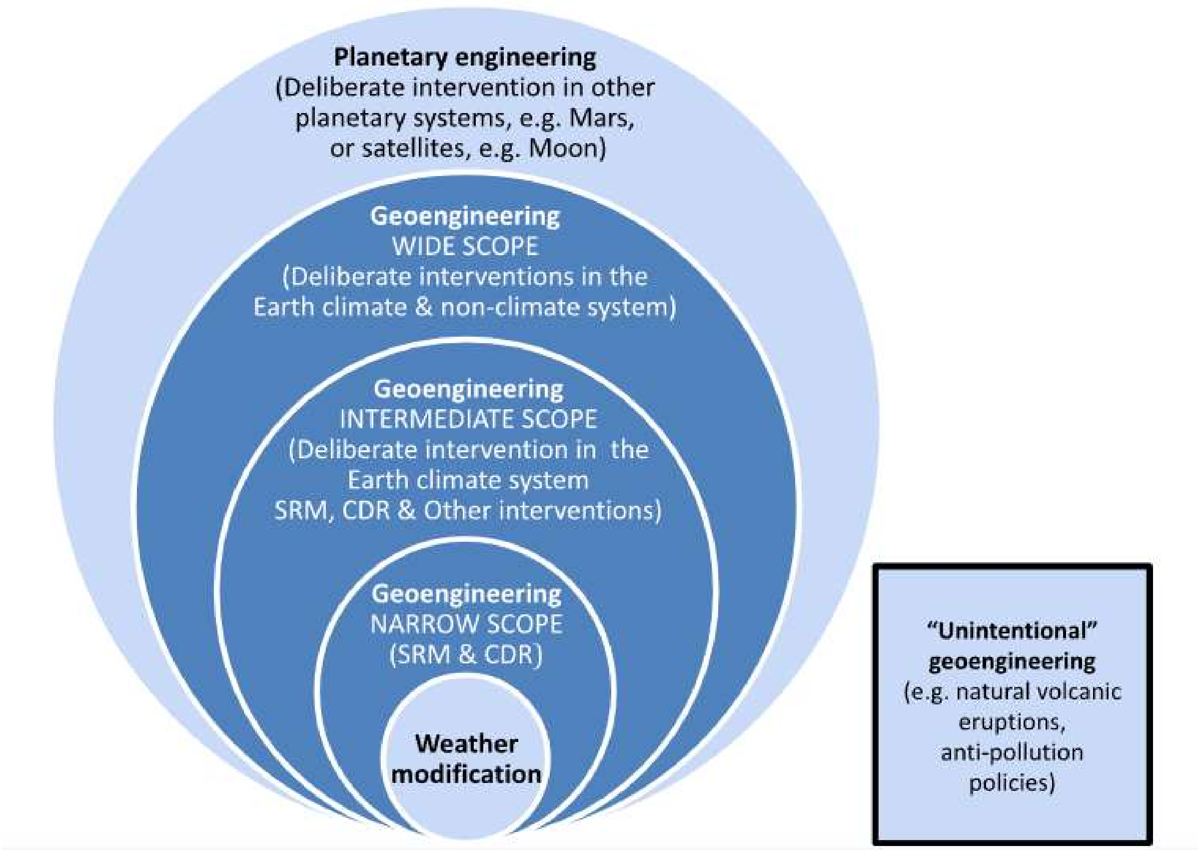
The Royal Society’s 2009 principal definition of geoengineering can be regarded as a broad political definition. It aims to introduce a new tool within the accepted portfolio of actions to respond to climate change, together with mitigation and adaptation (see Table 2). This political nature is more explicitly stated when the Royal Society refers in 2009 to geoengineering as a “relatively new policy area”, in comparison to mitigation and the most recent adaptation, an area that is defined as with no or only few regulatory or governance frameworks in place aimed at controlling geoengineering activities. On the other hand, the auxiliary definition of “geoengineering proposals” that we identify with the means to modify the Earth climate system, seems to refer to

[39] Shepherd & WGGC (2009, p. 1), underlying added, edited.
[40] Shepherd & WGGC (2009, p. 6).
[41] IPCC (2012, p. 2), quoted in IPCC pre-AR6 glossary, underlying added, edited.
[42] Shepherd & WGGC (2009, p. 1). Note that the Royal Society in the Shepherd & WGGC (2009) report and others take a narrower scope of SRM than IPCC (2012), interpreting solar radiation literally, only including climate interventions of incoming solar radiation and not of outgoing radiation. However, the Royal Society (2025) report follows the same scope as the IPCC (2012) for SRM, including both incoming and outgoing radiation. See Annex 2.A.
[43] IPCC (2012, p. 2).

the broad set of interventions that fall within the principal definition for its technical and ethical evaluation. The IPCC (2012) definition of geoengineering seems to follow the blue-print of the Royal Society, combining the principal and auxiliary definitions and adding a few clarifications that are useful for our analysis.

To avoid confusions in the different meanings of the term geoengineering we distinguish between three typical scopes of the neutral use of the term geoengineering found in the literature that we conventionally name as narrow, intermediate and wide scope (Figure 3, summarized in Annex 2.B). The most important scope in the authoritative reports is the narrow scope (e.g. Shepherd & WGGC, 2009; IPCC, 2012; IPCC, 2019) that focus on SRM & CDR as deliberate interventions to the Earth climate system.

Figure 3. Typical narrow, intermediate and wide scopes of geoengineering neutral definition in dark blue plus upper and lower practical boundaries of planetary engineering and weather modification, typically out of the scope of geoengineering, in light blue. Any reference to "unintentional" geoengineering is improper relative to the definitions of IPCC and Royal Society (see Annex 2.B)[44].



We also identify other terms associated with geoengineering that refer to higher practical

[44] All over the document we use the terms "deliberate" and "intentional", as well as "non-deliberate" and "unintentional" as synonyms respectively.

domains (e.g. planetary engineering) and lower ones (e.g. weather modification[45]) than those identified within the typical scope of the term geoengineering. This analysis is also required for the national and international authorities in charge of understanding or designing the ethics and governance systems, because any SRM intervention could also be repurposed, e.g. for planetary engineering (e.g. terraforming other planets or satellites (Symes, 2024b)) or weather modification (e.g. protecting urban populations during weeks of extreme heatwaves (Symes, 2024b)) (see Figure 3)[46]. Repurposing works across domains, from interventions with a main aim of weather modification (e.g. protecting biodiversity such as coral reefs from extreme heatwaves) to SRM (e.g. alleviating climate change impacts for decades). This is shown by the exemplary case of the Great Barrier Reef Restoration and Adaptation Program (RRAP)[47]. This is a weather engineering research experiment of Marine Cloud Brightening (MCB) because of its primary aim, but with possibilities to repurpose its interventions as SRM to alleviate negative consequences of climate change[48]. The practical possibilities of repurposing SRM into planetary or weather engineering and vice versa, is accompanied by parallel practical possibilities of commercialization of these repurposed interventions that could work as enablers or barriers to responsible research of SRM. Hence the importance of the ethics and governance of SRM research of widening the lenses of democratic control of commercialization from an exclusive focus on SRM to one that accounts for the broader possibilities of commercial uses of such technology, whether by private or public agents (see EGE, 2024).

In the following section we focus on the terminological analysis of the term SRM and its ethical justification, one of the main two categories of geoengineering in its narrow scope. For a brief explanation of the abandonment of the term geoengineering in the current authoritative reports, see Annex 2.E.

2. Terminological analysis of the current landscape of SRM and introductory ethical justification

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[45] To understand the difference between weather modification, it is useful to introduce the technical distinction between climate and weather, which may not appear in all natural languages associated with different terms. As the IPCC AR6 glossary states "In a narrow sense, climate is usually defined as the average weather, or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system." (IPCC, 2021).

[46] The Advance Research and Invention Agency (ARIA), the governmental agency of the UK in charge of investing in breakthrough social and economic technological innovations, explicitly recognizes the possibility of repurposing SRM interventions as part of the research program Exploring Climate Cooling (Symes, 2023, 2024a, 2024b).

[47] https://gbrrestoration.org/

[48] This is the description of the Royal Society "overview of publicly disclosed SRM field experiments" "Project: Great Barrier Reef Restoration and Adaptation Program (RRAP) (2020 – Present). Description: [...] This project has tested ship-borne sea salt spraying devices to evaluate the potential of marine cloud brightening to protect the Great Barrier Reef. The first experiment was conducted in March 2020, and further work is ongoing" (Royal Society, 2025, p. 96, edited). We partly disagree to call RRAP an SRM field research experiment, but we understand the purpose of the simplification. It is a weather modification research experiment as it is stated in its main aim "using MCB sprayers with the aim of assessing the technology for protecting the coral from bleaching by oceanic heatwaves" (Royal Society 2025, p. 86) and the name locates it as part of an adaptation program.

2.1. Current terminological analysis of the concept of SRM for ethics and governance

Our terminological analysis of the concept of SRM shows that in the most authoritative reports (e.g. Shepherd & WGGC, 2009; IPCC, 2012 quoted in IPCC, 2019; IPCC, 2021; COMEST, 2023; UNEP, 2023; EGE, 2024; Royal Society, 2025) and other relevant academic literature (e.g. Biermann et al., 2022; Parson et al., 2024) two umbrella terms solar radiation modification (SRM) and solar geoengineering (SG) are used with similar scope, solar geoengineering currently being the most popular in the media (Turner, 2025), and solar radiation modification the most used in the latest authoritative science-policy reports (e.g. IPCC, AR6; EGE, 2024; Royal Society, 2025). In turn, these umbrella terms abbreviations (SRM and SG) are expressed in different full forms with comparatively more neutral, negative and positive connotations (see columns 1-3, Table 3). We have also included a reconstructed main aim or end of the activity of SRM based on the IPCC (2012, quoted in 2019) glossary definition of geoengineering, a reconstructed full-scope of SRM that captures the means of intervention, as well as the main variables of modification in the Earth climate system that help to define the scope of what is understood as SRM in the literature (see columns 4-6, Table 3). Finally, we include the term climate cooling as a novel alternative to SRM and SG that is gaining popularity after the ARIA Exploring climate cooling research program, the most highly-funded SRM research program in history (ARIA, 2025; Turner, 2025).

Table 3. Terminological analysis of SRM and SG umbrella terms: different names and connotations (neutral, negative, positive) but similar main aim, scope and variables of modification.

Umbrella term	Umbrella term (full form)	Comparative connotation	Reconstructed main aim (end)	Reconstructed scope (means of modification)	Variables of modification
SRM	Solar radiation modification	Neutral[49]	Alleviate impacts of climate change including adverse outcomes for health and environment (see section	Stratospheric aerosol injection (SAI), marine cloud brightening (MCB) (main categories) & other climate interventions (e.g. Cirrus Cloud Thining (CCT)) that significantly modify incoming solar radiation (short-wave radiation) or outgoing trapped	(i) reflectivity: modification of reflectivity of surfaces (albedo); (ii) solar constant: modification of effective solar constant;
	Solar radiation management	Negative[53]			
	Sunlight reflection methods	Positive[54]			

[49] Royal Society (2025).

[53] Royal Society currently considers the term management more negative than modification and changed it from its 2009 report. Following recent widespread practice, we use the same acronym (SRM) but refer to it as 'Solar Radiation Modification'; 'management' might imply a degree of control that, given current understanding, is impossible." (Royal Society, 2025, p.13).

[54] Turner (2025).

SG	Solar geoengineering	Neutral[55] or negative[56]	2.2 and Annex 1, Box 1).[50]	radiation (long-wave radiation) (see Annex 2.A), used as single interventions or in combination (“cocktail” SRM)[51] during different stages of its potential life cycle (e.g. indoor & outdoor research, deployment, etc.) and at different scales (e.g. small, large) (see Annex 2.C)	(iii) emissivity: modification of effective emissivity of the atmosphere.[52] (see Annex 2.A)
	Solar Geo	Positive[57]			
CC	Climate cooling	Positive[58]			

At the very least, the legitimate representatives of affected stakeholders, including humans, non-human animals and non-human entities and future generations (EGE, 2024), have to understand what SRM is to make any meaningful decision (EGE, 2024)[59]. Also, as noted with the term geoengineering, different umbrella terms used in the literature with different purposes carry different connotations and function as neutral, negative or positive attitudinal markers (Jamieson, 1996). This terminological analysis carries some limits, but if useful, more systematic reviews and empirical studies should be conducted to correct or validate our findings.

2.2. Ethical justification and SRM main aim

This Report considers that one of the most fundamental ethical questions that should structure debate of SRM ethics and governance is, “Why should we do SRM, if at all?” which is, within an aims-based approach, equivalent to the question, “What is the main aim of doing SRM?”. First, defining the practical main aim limits the range of ethically permissible (e.g. the non-commercial or commercial use of SRM to alleviate climate change impacts) or impermissible actions (e.g., unilateral, military or hostile use of SRM). Second, an aims-based approach requires articulation with other important ends within SRM (e.g. research, deployment, monitoring) and between SRM and other actions (e.g. cutting emissions, CDR, adaptation). For example, typically the practical main aim of SRM research is to contribute to generalizable knowledge or resolve

[55] The Alliance for Just Deliberation on Solar Geoengineering (DSG)(2025), NASEM (2021).

[56] Biermann et al. (2022).

[50] Typically as a potential part of a portfolio of other responses (e.g. cutting emissions, CDR, adaptation, etc.) (e.g. Shepherd & WGGC, 2009, IPCC, 2012:2, Royal Society, 2025).

[51] There is a limited scientific literature that study multiple interventions also known as “cocktail geoengineering”, for example the combination of two short-wave radiation interventions (MCB + SAI) (Cao et al., 2017) or a combination of short- and long-wave interventions (SAI + CCT) (Boucher et al., 2017).

[52] Symes (2024a).

[57] SolarGeo (2025).

[58] ARIA (2025).

[59] This is captured in EGE (2024) with the ideas of “democratic control” and SRM as an intervention in the “global common good: a resource that serves the collective interests of humanity and which cannot be claimed or owned by any single entity” (EGE, 2024, p.21) of the “planetary environment” or Earth climate system. Democratic governance of SRM presupposes that at least the legitimate representatives of those affected by SRM understand what it is and what are the consequences of including SRM or not in the response portfolio to climate change impacts.

uncertainties about different uses or non-uses. Different types of SRM research are captured by different stages of the SRM climate interventions' life cycle (see Annex 2.C where we present EGE's four stages of SRM governance). However, the practical main aim of potential deployment of SRM is alleviating impacts of climate change, including adverse outcomes for health and environment.

As mentioned above, military or hostile use of SRM also falls within the discussion about SRM practical aims. In principle, there is a broad agreement in the literature of SRM ethics and governance that military or hostile aims should be ruled out both as the main aim of SRM or as secondary aims (EGE, 2024). However, the question remains: if SRM research is ethically permissible, how can we govern an intervention with potential "dual-uses" (EGE, 2024; Royal Society, 2025) and significant geopolitical (EGE, 2024) or security dimensions (Corry et al., 2024). To responsibly determine what the practical main aim of SRM is (if any) presupposes and requires an explicit ethical justification as discussed in the following section.

2.3. Ethical justification of SRM research and deployment: an overview

Before asking what the ethics and governance of SRM research principles are (see Chapter 5), we first require a general justification of its ethical permissibility or a "positive case" for SRM deployment (Jamieson, 1996). That is, before asking about SRM research principles, we should ask three basic questions. First, a technical question, namely, is SRM a potential effective means to alleviate climate change impacts? Second, if technically possible, is SRM ethically permissible? Third, if ethically permissible, what would be its role in the response portfolio of actions to climate change?

The main authoritative reports consider that SRM deployment is technically feasible and that SRM research is ethically permissible if conducted according to appropriate principles of ethics and governance (e.g. COMEST, 2023; EGE, 2024; Royal Society, 2025). To the third question about the role of SRM within the action portfolio of responses to climate change, most authoritative sources follow the current IPCC AR6 position: that SRM may be an ethically permissible option in the future if the risks associated with SRM deployment are considered smaller than the risks of climate change without SRM (Royal Society, 2025, p. 103). They also clarify that, in any case, it should not be the main policy or action in the portfolio to respond to climate change. And if ever to be deployed, it would be at best a supplement to the main mitigation actions of GHGs, mainly, cutting emission and CDR (e.g. IPCC, 2021; Royal Society, 2025). We will regard this as the general position of ethically permissible SRM research now and a potential lesser of two evils in the future (e.g. Jamieson, 1996; Shepherd & WGGC, 2009; Royal Society, 2025). For a more in depth analysis of ethical justifications see Annex 2.D.

This position contrasts with two extreme positions. On the one extreme, those who defend a "non-use" position to SRM. They regard SRM should be prohibited including research, small-scale outdoor research, large-scale experiments and deployment (Biermann et al., 2022), so they assign no role to SRM in the climate portfolio and consider it a distraction from core actions: cutting emissions and adaptation (see discussion on mitigation deterrence, Chapter 1, section 1.5). They recognize key risks of SRM including higher uncertainties of climate modification at regional level, security and militarization issues, and the problem of establishing sufficient level of evidence required, if any, before deployment for such experimental interventions. However, they contend that the main reason is the ungovernability of SRM in the current political system assuming effective global participation, inclusiveness and justice.[60] To put it more bluntly, those who advocate a ban on SRM research believe that introducing SRM will make things worse, not better (Geoengineering Monitor, 2025).[61] Defenders of this position includes exemplary cases of countries' proposal of "non-use" of SRM at the 6th United Nations Environment Assembly (UNEA-6) (Biermann & Gupta, 2024), and Mexico's announcement of a ban to all SRM experimentation (Biermann, 2023, Carabajal et al., 2025). These exemplary cases are closely related to the academic proposal of "non-use agreement" (NUA) to ban SRM (Biermann et al., 2022).

On the other extreme are those who defend an SRM deployment now (instead of a future possibility) as the best ethical alternative at hand in spite of the uncertainties and known risks. An example of this position is the US startup Make Sunsets, and its commercialization project of cooling credits based on stratospheric aerosol injection, which would amount to a small-scale non-research experiment of SRM deployment according to our definition of SRM (see Table 3, and Carabajal et al., 2025). Make Sunsets's ethical position could be described as direct action. They usually combine it with a critical view of academic research and government involvement (Carabajal et al., 2025).

2.4. Fundamental values for ethics and governance of SRM research

In this section we present a brief overview of fundamental values of ethics and governance of SRM. Technical authoritative reports on SRM (e.g. Royal Society, 2025) intendedly and explicitly simplify the discussion on ethics and governance of SRM research and mainly focus on ethical and/or governance principles, typically with the aim to operationalize them.

In Chapters 5 and 7, we perform a more detailed analysis of principles and ways to govern SRM, and their relationship to health.

[60] According to the authors SRM "is impossible to govern fairly and effectively in the current international political system, under assumptions of effective global participation, inclusiveness, and justice." (Biermann et al., 2022, p. 3).
[61] "The bottom line: geoengineering techniques do nothing to address the root causes of climate change, and evidence points to a high likelihood that rather than improving the climate, they would make things worse—potentially in catastrophic fashion." (Geoengineering monitor, 2025).

Table 4. EGE's (2024) fundamental values[62] of SRM ethics and governance

Substantive	Justice	**Justice**. SRM raises questions of equity and solidarity, distributive, procedural, epistemic and rectificatory (corrective) justice. Distributive justice includes intergenerational justice and consideration of interest of non-human nature[63]. Distributive justice aims to prevent individual or group agents from taking more of the good or less of the bad aspects of SRM in its life cycle including risk and potential benefits distribution.
	Inclusion	**Inclusion**. Particularly, in the form of participation in decisionmaking processes (valuing public participation)[64]. Inclusion in the decision making process aims to prevent capture from interest groups including industry, researchers, climate activists, developed countries or any individual or group agents that could be able to manipulate the design of ethics and governance of SRM to their specific interest instead of the common good (see Chapter 6 on public engagement of this report)
	Reciprocal relationship	Justice and inclusion are reciprocal and mutually reinforcing because justice requires inclusion and inclusion promotes justice[65].
Procedural	Transparency	**Transparency at the level of scientific research into SRM**. Includes initiatives that are explicitly labelled or not as SRM, transparency in communicating research objective, processes, results (positive and negative or null), funding, conflicts of interests, recognition of uncertainties regarding findings[66].
		Transparency at the level of political communication with civil society on SRM research (and eventual deployment). Includes the groups involved and specific interests, strategies implemented and their rationale, avoiding manipulation and guaranteeing integrity of information[67].
	Accountability	**Accountability attribution.** Includes, recognizing liability, including legal liability, setting suitable penalties and compensation mechanisms, responsibility towards wider society in space and time, compliance with rule of law and global justice, fair sharing of risks and benefits, due process for large scale deployment[68].
	Reciprocal relationship	Transparency and accountability are reciprocal because it is not possible to attribute responsibility without knowing basic facts[69]. They also are procedural standards to minimize biases and errors to create a legitimate decision making process.

[62] Here we will use the term values, following the Oxford Principles for geoengineering (Rayner et al., 2013), rather than the term ethical principles that is used in the EGE's (2024) opinion, to distinguish the broader and foundational category from the ethical and governance principles analyzed in Chapters 5 and 7.
[63] EGE (2024, pp. 30-31).
[64] EGE (2024, p. 31).
[65] EGE (2024, p. 31).
[66] EGE (2024, pp. 29-30).
[67] EGE (2024, pp. 29-30).
[68] EGE (2024, p. 30).
[69] EGE (2024, p. 30).

Our reconstruction of EGE's position is just one of many possible systematizations of such fundamental values. The richer and deeper our understanding of these fundamental values, the more conceptual resources responsible agents will have to deal with operationalization of ethics and governance of SRM. One potential contribution from practical philosophy to the richer and deeper understanding of these fundamental values will certainly come from extending contemporary theories of justice in the case of SRM research analogous with biomedical research ethics (e.g. London, 2022; Miller, 2025).

3. Final considerations

In this chapter we aimed to introduce a terminological analysis inspired by the methodology of "rectification of terms" (Jamieson, 2014). We believe that terminological analysis should be the first logical step of ethics and governance of SRM, which should be continued as the evidence and terms that refer to SRM evolve. We identified three general positions: the middle ground is that SRM research is ethically permissible now, and deployment would be ethical as a potential lesser of two evils in the future (e.g. Jamieson, 1996; Shepherd & WGGC, 2009; Royal Society, 2025). The two extremes are the non-use (neither research nor deployment are permissible now or in the future) or direct action (SRM deployment is ethically necessary now). This was presented as an introductory ethical justification of SRM to capture very broad lines and ideas that might be lost in the technical details and complexity of the subject.

Part II. The SRM—health nexus

Chapter 3. Bibliographical review: the possible health impacts of SRM[70]

Introduction

This chapter provides an overview of the existing academic literature addressing the relationship between Solar Radiation Modification (SRM) and human health. As research on SRM continues to expand, studies touching on its potential health implications have increased in number but remain dispersed across different disciplines and methodological approaches. This review aims to map, organize, and synthesize that body of work.

Section 1 describes the methods used to identify relevant publications, including narrative and rapid review strategies, searches in academic databases, the use of a specialized database from the Degrees Initiative, and contributions from field experts. Section 2 outlines how the initial corpus was refined through inclusion and exclusion criteria and how the final selection of texts was consolidated. Section 3 presents the main characteristics and thematic patterns of the reviewed literature, examining who conducts this research, the institutional and funding landscapes that support it, and the substantive issues addressed. These include aerosol-related health effects, temperature-driven impacts and changes in UV radiation, air quality, and ozone dynamics.

This review synthesizes the available evidence and maps current research gaps and thus provides a foundation for understanding how SRM might affect human health.

1. Methods

To examine the current state of the literature on the subject with methodological rigor, a narrative and rapid review were undertaken. This process entailed the identification, critical appraisal, and synthesis of peer-reviewed publications relevant to the intersection of Solar Radiation Modification (SRM) and human health. The literature search was conducted using three complementary strategies: first, general academic search engines—including PubMed and Google Scholar—were employed to capture a broad spectrum of scientific output; second, a specialized database from Degrees Initiative[71] was used to refine the search within the thematic scope of the study; third a curated selection of key texts recommended by leading experts in the field.

Eligibility for inclusion was determined by the material's relevance to SRM and health-related issues, also by inclusion and exclusion criteria (Table 5). Following selection, all texts were systematically coded based on the specific sub themes they addressed. This coding process facilitated the thematic organization and analytical comparison of the literature corpus. Following the initial broad selection, a screening process was conducted to refine the corpus and determine the final set of texts subjected to in-depth analysis.

[70] Main contributors: Marco Agustoni, María Florencia Santi and Inés Camilloni.

[71] The Degrees Initiative is an Non-Governmental Organization (NGO) dedicated to building the capacity of developing countries to evaluate solar radiation modification or solar geoengineering. See: https://www.degrees.ngo/

1.1. Narrative review: Degree's database and expert-selected texts

Considering the emergent stage of this research area, coupled with the conceptual and argumentative diversity present in the existing literature, undertaking a systematic review was deemed methodologically inappropriate (systematic reviews are typically extensive and designed to deliver comprehensive and exhaustive syntheses). Due to the temporal constraints of the project, a rapid review was identified as the most suitable approach for generating timely and relevant evidence[72].

The database[73] provided focuses on solar radiation modification from ethical and philosophical perspectives. It contains 247 documents, including academic and grey literature (e.g. articles, chapters, books and reports), as well as web pages. This database serves to contextualise the research problem, but does not provide any specific articles on the intersection of SRM and its human health effects.

In addition to the database, expert contributions were asked to identify literature that might have been overlooked. These expert-selected materials[74] were incorporated into the broader review to enhance its completeness and ensure a more comprehensive coverage of the field.

1.2. Bibliographic review and selection

The bibliographic review was carried out using two academic search engines: PubMed and Google Scholar. The results of these searches are presented in Tables 3.1 and 3.2 from the Annex, respectively. Each table outlines the search terms used, the number of results retrieved, their thematic relevance, and whether they were included in the first corpus.

These searches were designed to ensure a comprehensive and diverse set of sources, reflecting both biomedical and interdisciplinary perspectives on the intersection between SRM, health, and related climate change issues. The selection process emphasized transparency and replicability: search terms were chosen based on their relevance to the research questions, and results were evaluated systematically.

Following this initial review based on a predefined set of keyword strings, a second search was conducted using an expanded set of terms, from July 2025. This subsequent search was informed by expert review and aimed at addressing potential omissions or limitations identified in the first round of results. The new keywords and their corresponding search results are also

[72] This form of review prioritizes interpretative analysis and critical appraisal, seeking to enhance conceptual clarity and deepen understanding of the subject under consideration (Sukhera, 2022).

[73] The database was provided by Jesse Reynolds, Chief of Staff at the Degrees Initiative.

[74] Inés Camilloni, Ph.D. in atmospheric sciences, provided an article that had not appeared in the initial search. Timothy Daly, Ph.D. in philosophy, contributed another such article, and Lili Xia, Ph.D. in atmospheric sciences, also provided relevant texts. We thank the experts for their contributions, especially to Lili Xia who shared with us an overview of several articles.

documented in the tables that follow (Table 5), allowing for a transparent comparison across the different phases of corpus construction.

Since Google Scholar does not support complex Boolean operators, truncation, or grouping with parentheses as in PubMed, the search strategy had to be simplified. Key terms and exact phrases most representative of the topic were prioritized to ensure the functionality and relevance of the results. This adaptation preserves the thematic coherence of the original search, albeit with reduced technical specificity due to platform limitations.

In this first selection phase inclusion and exclusion criteria were applied, in both searches, these are summarized below in Table 5. These criteria were essential for filtering out non-relevant material and ensuring that the final selection of texts would support a meaningful analysis of the connections between SRM and health.

The subsequent section details how the initial corpus of texts was coded and refined through a second round of screening.

2. Consolidating the literature base

Following the rapid review, the expert-selected texts, and the Degree Initiative's database search, a lead sheet was created with 72 texts identified as potentially relevant based on their abstracts and an initial review. This selection was coded according to the following categories: *relevance*, *title*, *author*, *focus on geoengineering*, *focus on health*, *analysis/observation*, *year of publication*, *DOI*, *publisher*, and *additional comments*. Many of these texts addressed either geoengineering or health individually; only a few engaged with both topics simultaneously. One of the core inclusion/exclusion criteria was the requirement that selected materials explicitly address the intersection between these two themes. After applying this second level of filtering, only 17 texts were ultimately selected for in-depth analysis and will be presented in the "Literature Analysis" section.

It should be noted that the inclusion criteria were deliberately expanded in certain cases to accommodate texts that explored the relationship between climate change and health in broader terms. This broadening aimed to enhance the depth of the analysis.

2.1. Inclusion and exclusion criteria

Table 5. Inclusion/exclusion criteria for the first selection review

Categories	Inclusion Criteria	Exclusion Criteria
Language	English / Spanish	All other languages
Topic	● Intersectional analysis of geoengineering, SRM or SAI, and their health-related implications for the Global South. ● Intersectional analysis between geoengineering and human health effects: - Geoengineering as Solar Radiation Modification (SRM), Stratospheric Aerosol Injection (SAI), climate intervention, reflective particles. - Mental health, public health, human health, etc.	● Broad overview of climate change impacts, geoengineering approaches, and health-related issues.
Literature type	● Academic literature. ● Peer reviewed articles, review articles, book chapters.	● Inaccessible documents or preprints. ● Grey literature as: - News articles, blogs, Institutional material, workshop and conference presentations.

2.2. Limitations

During the literature review process, only a limited number of studies were found that explicitly addressed the intersection between SRM and health-related issues. As will be further developed in the following section, this lack of specific literature led to a partial reconsideration and loosening of the initial inclusion criteria in order to expand the analytical corpus. In this context, we chose to include works that maintained a focus on SRM and health, while also offering relevant insights from Global South contexts. This decision allowed for a broader range of sources and enriched the analysis by incorporating critical and situated perspectives.

3. Analysis: academic literature reviewed

The literature reviewed in this study consists exclusively of peer-reviewed articles identified through systematic database searches and complemented by contributions from our professional networks. The median publication year of the selected papers is 2021, with the corpus spanning from 2016 to March 2025. This distribution reflects a marked intensification of scholarly attention to SRM—particularly Stratospheric Aerosol Injection (SAI)—and its potential health impacts in recent years, despite the fact that these issues have been discussed for several decades in scientific and policy debates.

3.1 Researchers

To better understand who is driving research on SAI and its potential health implications—as well as the motivations and backgrounds shaping these efforts—we analyzed the nationalities of the authors represented in our corpus. Author nationality was determined using the nationality of their institutional affiliation as a proxy, or, when available, the author's self-declared nationality.

The analysis reveals a striking geographic imbalance: researchers from the Global North represent approximately 77% of the total, while only 23% are affiliated with institutions in the Global South. Of the 74 authors identified, 55% are based in the United States, reflecting the significant funding and institutional support that SAI research receives from U.S. sources, as we will discuss later. Authors affiliated with European Union institutions account for an additional 22%.

Within the Global South, the majority of authors are located in the developing Asia–Pacific region (16%), with Chinese researchers comprising roughly half of that group (8%). African researchers constitute around 5% of the total, mainly from South Africa, with one author from Côte d'Ivoire. Notably, no authors affiliated with institutions in Latin America or the Caribbean were identified in the corpus.

3.2 Institutions, support and funding

Another critical dimension of SAI and SRM research concerns the institutional and financial support that enables these studies. Our analysis indicates that funding is concentrated in a small number of specialized research programs and leading academic institutions.

Among dedicated funding programs, the DECIMALS Fund (Developing Country Impacts Modelling Analysis for SRM), renamed in 2022 as the Degrees Modelling Fund (DMF), financed five studies in our corpus. The U.S. National Science Foundation (NSF) supported three studies, while China's National Key Science Program for Global Change funded two additional studies. Other funding sources included the Simons Foundation and Silver Lining.

Universities also play a significant role in supporting this research. Harvard University contributed support for two studies, while the University of Michigan, the University of Thessaloniki (Greece), and the University of Amsterdam were also notable contributors. This pattern highlights the concentration of resources in leading research institutions, primarily in the Global North, which aligns with the observed author distribution.

3.3 Analysis: themes, concepts and patterns

It is important to clarify that, for the purposes of this analysis, our focus lies specifically on the potential effects that could result from the actual interventions of this technology, as well as those that can already be inferred from the characteristics of its proposed aerosol candidates components. This focus intentionally moves beyond potential changes in variables exogenous to the intervention itself. The primary objective is to address the potential health impacts directly associated with the interventions of SRM in the form of SAI, rather than the broader health consequences of climate change that might otherwise be examined within a risk–risk analytical framework. Although both issues are closely interrelated, this review seeks to delimit its scope to the existing body of literature situated at the intersection between SAI (as a SRM strategy) and human health.

When analyzing the bibliographic corpus, we found that the selected texts approach the topic in a wide variety of ways. Some focus on direct health impacts of the particles that might be used, while others examine potential health effects inferred through modeling—an aspect we will elaborate on in the next section. Still others conduct comparative assessments, including risk–risk, risk–benefit, or trade-off analyses. Notably, only one of the papers explicitly aims to provide an overview of the various pathways through which SAI might affect global public health (Tracy et al., 2022).

It should be noted that many of the studies address more than one of these perspectives simultaneously. For example, some combine the discussion of direct health impacts with broader reflections on risk or risk analysis, while others adopt a review-oriented approach exploring possible beneficial trade-offs between SAI and health from a more general standpoint.

To facilitate the presentation of results, we organized the papers into thematic clusters according to the issues they address or the analytical frameworks they employ. This grouping also reflects the fact that many of the authors engage in dialogue with each other, referencing or building upon the perspectives and conclusions of their peers. The main thematic categories identified are:

1. Direct or potential impacts of aerosols on human health.
2. Potential impacts of temperature changes—including temperature related mortality, vector-borne diseases, effects on the hydrological cycle and others.
3. Effects on solar ultraviolet (UV) radiation, air quality and ozone dynamics.

We acknowledge that several topics we and other authors consider highly relevant are notably absent from this grouping—such as the health impacts of cooling in cold and low-income regions, potential effects on drinking water supply, or on biogeochemical cycling. These omissions reflect the specific areas of focus chosen by the authors of the reviewed studies, rather than deliberate exclusions within our own analysis. Before proceeding, however, it is important to clarify the types of modeling approaches used in the projections presented in several of the reviewed papers.

3.3.1 Climate modelling and projections

To contextualize these modeling approaches, it is useful to briefly outline the climate-modeling frameworks that underpin much of the current research on SRM in the form of SAI. These computer-based climate models provide the primary source of evidence for evaluating the feasibility, risks, benefits, and potential unintended consequences of SRM, enabling comparisons between a hypothetical SAI world and a non-SAI world.

Extensive research is underway in the scientific community to understand the feasibility, risks, benefits, and potential negative consequences of SRM strategies to reduce surface temperatures. The primary source of evidence for the effect of SRM comes from computer-based climate models, which represent a subset of the same models used in Intergovernmental Panel on Climate Change (IPCC) projections of future climate change, and allow us to assess climate outcomes in a potential SAI versus non-SAI world. Insights from real-world events, such as volcanic eruptions, support these models.

Numerous climate modelling initiatives, such as the Geoengineering Model Intercomparison Project (GeoMIP) (Kravitz et al., 2011, 2015), the Stratospheric Aerosol Geoengineering Large Ensemble (GLENS) (Tilmes et al., 2018) and the Assessing Responses and Impacts of Solar climate intervention on the Earth system with Stratospheric Aerosol Injection (ARISE-SAI) (Richter et al., 2022) have used global climate models (GCMs) to simulate various SRM strategies. These GCMs datasets are publicly available (access details can be found in the cited papers) and provide a consistent experimental framework for assessing the potential impacts of SRM (see Table 6).

Table 6. Some examples of computer-based climate models

	Models	Inputs	Targets	Methods
GeoMIP 6	Multi-model Intercomparison Project *(6 GCMs)*	High GH emissions *(SSP5-8.5)*	Medium Emission *(match SSP2-4.5)*	Solar Dimming & Sulfur Injection *(4 Latitude)*
GLENS	Single Model *(20 Ensemble members)*	High GH emissions *(RCP-8.5)*	Maintain 2020 temperatures	SO_2 Injection *(4 Latitudes and 1 Longitude)*
ARISE-SAI	Single Model *(10 Ensemble members)*	Medium GH Emissions *(SSP2-4.5)*	Maintain 1.5 °C above Pre-industrial levels	Stratospheric Aerosol Injection *(4 Latitude)*

The GeoMIP project started with four experiments that simulated the potential impacts of solar dimming (G1 and G2) and stratospheric aerosol injection (G3 and G4) on the Earth's climate system and subsequently evolved into more rigorous and comprehensive experiments known as G6solar and G6sulfur in GeoMIP6. In GeoMIP6, SRM is simulated by six different global climate models (CESM2-WACCM , CNRM-ESM2-1, IPSL-CM6A-LR, MPI-ESM1-2-HR, MPI-ESM1-2-LR and UKESM1-0-LL) either by reducing the solar constant (G6solar) or through the injection of stratospheric sulfur aerosols (G6sulfur) with a target of reducing global mean temperature under the high-emission SSP5-8.5 scenario to meet the global mean temperature projected by the intermediate SSP2-4.5 scenario. The purpose of the GeoMIP experiments is to evaluate the associated responses, for different systems and sectors, of a climate similar to the target (e.g. SSP2-4.5) achieved through SRM rather than by reducing greenhouse gas emissions.

The GLENS project includes a suite of simulations made with the NCAR Community Earth System Model using the Whole Atmosphere Community Climate Model CESM1 (WACCM) as its atmospheric component. The simulations consist of simultaneous injection of sulfur dioxide (SO2) into the stratosphere at four locations, 30◦S, 15◦S, 15◦N, and 30◦N at 180◦E and at an altitude around 5 km above the climatological tropopause height at the injection latitudes. The goal of the GLENS geoengineering simulations is to maintain the global mean surface temperature and the interhemispheric and equator to pole surface temperature gradients at 2020 levels over the period 2020–2099 under the high GHG emission scenario RCP8.5.

The ARISE-SAI project is a set of 10-member ensemble simulations with the Community Earth System Model version 2 (CESM2). The simulations called ARISE-SAI-1.5 model the introduction of stratospheric aerosol injection at four injection locations (15°S, 15°N, 30°S, 30°N) at 180° longitude and an altitude of ~21 km in the year 2035 to keep the global mean surface air temperature near 1.5°C above the pre-industrial value in combination with the SSP2-4.5 emissions scenario. ARISE-SAI-1.5 simulations commence in 2035 with a target of maintaining global surface temperatures at 1.5°C above pre-industrial levels. The ARISE-SAI-1.5 simulations are more realistic than other SAI experiments that run under a no-mitigation high emissions scenario.

3.3.2 Thematic analysis

- **Direct or potential impacts of aerosols on human health.**

When analyzing the potential health impacts of SRM through SAI, it is necessary to consider the effects of the materials that compose the aerosols proposed for injection. Authors such as Effiong and Neitzel examine the available information on these materials—the potential candidates for SAI—and their implications for human health as sulfur dioxide, sulfuric acid, hydrogen sulfide, carbonyl sulfide, black carbon, aluminum compounds and barium compounds. Similarly, Ghirga (2025) explores the possible mental health impacts of aluminum oxide, a proposed substitute for sulfate aerosols.

Although injection would take place in the stratosphere on continuous and prolonged exposure over the years, it is expected that, over time, the injected particles would eventually settle back to the surface (Eastham et al., 2018b). As Effiong and Neitzel note, “due to atmospheric circulation and gravitational deposition, large-scale population exposures to atmospherically injected SRM materials will almost certainly occur after their deployment” (Effiong & Neitzel, 2016, p. 3). This underscores the need to assess not only the intended climatic effects of SAI but also the potential toxicological consequences and overall risk-benefit profile to health and ecosystems associated with prolonged or widespread exposure to each of these different candidate substances.

The magnitude of such impacts would obviously depend on the quantities involved. In this regard, Effiong and Neitzel (2016) acknowledge inconsistencies between established exposure limits for occupational and community settings. Nevertheless, drawing on available toxicological and epidemiological data, they identify potential hazards associated with the materials most frequently considered for SAI. Potential SRM aerosols show evidence of respiratory, cardiovascular, and neurological effects on human health, and many also exhibit hematological, dermal, reproductive, and other systemic impacts—except for barium titanate, for which data were insufficient (Ghirga, 2025; Tracy et al., 2022; Effiong & Neitzel, 2016).

In the same line of analysis, Ghirga asserts that the existing literature clearly links elevated aluminum levels in the central nervous system to the development of Alzheimer’s disease, multiple sclerosis, and Parkinson’s disease. He further raises concern about the environmental amplification of such risks, emphasizing that one of the greatest current environmental threats to health is air pollution. In this regard, he recalls that “in 2019, 99% of the world’s population was living in places where the World Health Organization air quality guideline levels were not met” (Ghirga, 2025, p. 3), and that ambient outdoor air pollution was estimated to have caused 4.2 million premature deaths worldwide that same year—89% of which occurred in low- and middle-income countries. In this context, the prospect of increased risk resulting from the deployment of aluminum oxide becomes particularly concerning.

- **Potential impacts of temperature changes—including temperature related mortality, vector-borne diseases, effects on the hydrological cycle and others.**

Temperature-attributable mortality is one of the most widely examined health issues related to SAI—and one of the most frequently discussed topics in the reviewed corpus. As Harding (2024) notes, a central concern is the uneven distribution of temperature-related impacts. While some regions may experience reductions in heat-related mortality under SAI scenarios, others may face heightened risks. Such uneven distributions extend to multiple temperature-sensitive phenomena, including the geographic expansion of vector-borne diseases (Carlson et al., 2022; Hussein et al., 2024), alterations in the hydrological cycle, and changes in the frequency or severity of extreme weather events (Tracy et al., 2022; Obahoundje et al., 2023; Kuswanto et al. 2022; Wang et al. 2023; Patel et al., 2023; Harding et al., 2024).

The net effects of SAI on public health are therefore highly context-dependent, varying across regions, populations, and socioeconomic conditions. Assessments of potential health impacts must account not only for aggregate global effects but also for spatial and social inequities, which require regionally specific analyses.

Recent regional modeling and analysis efforts—many supported by the Degrees/DECIMALS initiative—provide valuable insights into these dynamics. Within our corpus as seen before, studies focus only in two regions of the Global South: Africa (Obahoundje et al., 2023; Patel et al., 2023) and the developing Asia–Pacific region (Kuswanto et al., 2022; Wang et al. 2023). The studies vary considerably in focus and methodological approach.

For instance, Wang et al. (2024) analyzed various scenarios (SAI-G4, RCP4.5, RCP8.5, and a 1980s baseline) for Beijing, finding that SAI under G4[75] would reduce heat-related excess deaths of the elderly (over 65s) relative to the emission scenarios RCP4.5 and RCP8.5 while increasing cold-related mortality in comparison with both scenarios. They concluded that the net effect on mortality of SAI vs the RCP4.5 scenario is relatively small, but emphasized that in aging populations overall mortality effects would be amplified: "[a]ging societies are already common, and the rest of the Global South will follow the trend in the next few decades. These demographics will greatly amplify both the heat-related mortality and cold-related mortality rates" (Wang et al., 2024, 13).

In the Indonesian Maritime Continent, Kuswanto et al. (2022) report that SAI impacts diverge from general expectations of reduced humidity and rainfall due to local territorial characteristics. These findings suggest that SAI could be particularly beneficial in mitigating climate-driven increases in wildfires and droughts, addressing region-specific challenges in Indonesia.

Similarly, Obahoundje et al. (2023) analyzed Africa by subdividing it into four regions and comparing G4 and RCP4.5 scenarios. While the regional impacts vary, SAI's cooling of continental surfaces is projected to increase the co-occurrence of dry events across all seasons, raising vulnerability to compound climate extremes. The authors further note that these changes could negatively affect multiple sectors, including agriculture, food security, water resources, energy, health, socioeconomics, and politics.

Patel et al. (2023) provide a more localized example for South Africa, using the GLENS simulation[76]. Their projections indicate both positive and negative effects of SAI: reductions in heat-related mortality and extreme heat events are anticipated, but drought severity may increase by a factor of three to six in some regions.

While these studies provide a detailed regional view, global-scale analyses offer complementary insights. Harding et al. (2024), assessing the impact of SRM on temperature-attributable mortality at a global scale, acknowledge substantial regional heterogeneity in outcomes. In their analysis, the Global South as a whole would tend to benefit from the cooling produced by SRM; however, they caution that quantitative risk–risk assessments cannot, on their

[75] One of the computer based models with SAI. See section 3.3.1.
[76] See Table 2.

own, serve as a sufficient basis for deployment decisions. This highlights a common trade-off: generalizing from global averages may obscure locally important effects.

Carlson et al. (2022) show that SAI strategies designed to offset warming do not guarantee uniform health benefits and may generate regional trade-offs within the Global South. One such example is malaria transmission: using a temperature-based malaria transmission function (R_0), Carlson et al. predict that SAI could reduce malaria risk in high-altitude regions of East Africa while increasing it in low-lying areas of West Africa and South Asia, demonstrating clear regional disparities in health outcomes.

Together, these global and regional studies underscore the complex, uneven, and context-dependent nature of SRM's potential impacts on temperature-related health outcomes, emphasizing the need for both high-resolution regional assessments and consideration of global-scale patterns.

- **Effects on solar ultraviolet (UV) radiation, air quality and ozone dynamics.**

Building on previous research into the public-health impacts of SAI, as discussed in Effiong and Neitzel (2016), Eastham et al. (2018b) conducted a quantitative assessment that incorporates epidemiological evidence to estimate how global mortality rates could be influenced by changes in air quality or UV-B exposure.

Other authors in the corpus also address this topic. In a broad review, Bias et al. (2019) identify potential impacts of UV-radiation action spectra on human health, including skin damage, vitamin-D synthesis, and phototherapy for psoriasis. However, they do not quantify these effects in relation to any specific SRM or SAI projections.

SRM's impact on air quality arises from both chemical interactions and radiative–dynamical feedback. Xia et al. (2017) investigated how two solar radiation strategies, SAI and solar dimming, affect surface ozone. Although both methods cool the planet at similar levels by reducing sunlight, their impacts on ozone concentration differ significantly. Sulfate injection causes a global decrease in surface ozone because enhanced stratospheric sulfate leads to ozone depletion and less ozone transported downward. However, the regional response varies depending on local atmospheric chemistry: in polluted, high-NOx[77] regions, ozone may decrease further, while in cleaner or more humid environments, it can increase. In contrast, solar dimming generally raises surface ozone by reducing humidity and slowing ozone destruction. Because surface ozone is a major air pollutant linked to respiratory and cardiovascular diseases, their results suggest that SRM could reshape air quality unevenly.

[77] Polluted areas with high levels of nitrogen oxides, typically urban and industrialized regions.

Eastham et al. (2018b) quantified that stratospheric sulfate geoengineering would reduce tropospheric ozone and UV-B exposure, leading to a net decrease in premature mortality from air pollution despite small increases in surface particulate sulfate.

Overall, current evidence suggests that moderate stratospheric aerosol injection could change global air quality and results highly depend on SAI scenarios and models. To fully quantify combined effects from $PM_{2.5}$[78] surface ozone, and UV-B exposure requires improved atmospheric chemistry–health coupling and region-specific exposure assessment.

4. Final considerations

This review highlights that, despite growing global attention to SRM and SAI, scholarship explicitly addressing their implications for human health remains limited and unevenly developed. Thus, there is a need to do more health related studies as well as health impact studies of cooling in cold and low income countries, including effects on drinking water and biogeochemical cycling. Nevertheless, the available studies converge on a broadly shared understanding: the effects of SAI would be unevenly distributed at the global scale. Regions already exposed to climate-related stressors are expected to experience the most pronounced changes, whether beneficial or adverse.

Authors working on Global South contexts consistently emphasize that structural vulnerabilities—including constrained economic resources, insufficient infrastructure, and weakened health systems—could intensify the health-related consequences of SAI. Because these regions are already disproportionately affected by climate change, the prospect of introducing SAI adds another layer of complexity to ongoing adaptation and public-health challenges. This recognition has contributed to a growing and increasingly sophisticated debate emerging in parts of the Global South.

Within this broader landscape, Latin America and the Caribbean present a distinct configuration of challenges and research needs. While the region shares certain vulnerabilities with other areas of the Global South, it also exhibits specific climatic, socioeconomic and health systems institutional characteristics that may shape the health implications of SRM in unique ways. At the same time, its comparatively limited participation in the scientific literature on SRM means that these regional particularities remain insufficiently examined and largely absent from current SRM discussions.

Given these findings, strengthening scientific production on SRM and its health impacts in Latin America and the Caribbean, including the region's particular challenges, emerges as a pragmatic and necessary step. Enhancing regional research capacity would allow for the identification of context-specific risks and potential co-benefits, support more accurate modelling of local conditions, and ultimately contribute to better-informed assessments of how SRM could interact with existing regional climatic and public-health dynamics.

[78] Particulate matter smaller than 2.5 micrometers.

By addressing these gaps, future research can provide the empirical foundations needed to conduct well-informed evaluations of climate-intervention proposals in a manner that reflects the specific realities of the region. Furthermore such information could support the design of policies that may prevent dangerous and risky outcomes or at least anticipate them with strong empirical studies regarding possible illnesses and harms, while also guiding the development of adequate infrastructures if SRM or SAI were to be accepted or deployed.

Chapter 4. Climate interventions and public mental health[79]

Introduction

This chapter addresses some concerns regarding SRM deployment in light of multi-level determinants of mental health, as a comprehensive analysis of SRM must weigh trade-offs, comparing the risks of inaction with the intended and unintended consequence of SRM deployment (Felgenhauer et al., 2025). Without such analysis, SRM policies risk overlooking psychosocial harms that could undermine their potential benefits, particularly for groups disproportionately affected by the risk of both climate change and the interventions to reduce its impacts.

1. SRM and public mental health: an analysis of tradeoffs

The sparse literature on SRM and mental health has not addressed the relationship explicitly from a public mental health perspective. Two aspects have been mentioned so far: the question of the mental health impacts of aerosols, and the potential impacts of sunlight reduction through SRM. Ghirga (2025) warns against the use of aluminium oxide as an aerosol in stratospheric aerosol injection (SAI) due to its possible interactions with the nervous system (see Chapter 3). Tanaka and Matsubayashi (2025) conclude their empirical study on sunlight and suicide by warning that "policymakers should carefully assess the potential unintended consequences of solar geoengineering" (p. 3) on this relationship. This suggests that one line of investigation could model the "heat-light" trade-off of SRM for its potential impact on biological determinants of mental health. That is, from the perspective of public mental health, in SRM, light reduction (due to increased reflection of sunlight) would be necessary to reduce temperatures, but there may be a trade-off to attain due to the negative impact of excessive light reduction on mental health. We stress that this trade-off would require empirical validation by the relevant experts.

When conceptualising mental health with practitioners and the public, Dykxhoorn et al. (2022) asked policy makers and members of the public to rate determinants based on their importance, that is, to what extent the determinant "provided relevant information considered to be meaningful to understanding public mental health," i.e. had a meaningful impact on one of the levels of public mental health (p. 3). The determinants receiving the highest importance scores at the individual level were trauma, income, and employment. At the family level, early life attachment & parenting received the highest importance score. The determinants rated as the most important at the community level were social support & networks, access to health & social care, and social inclusion & cohesion. At the structural level, displacement, inequality & inequity, and the welfare system received the highest importance scores.

We can analyse trade-offs of SRM deployment for public mental health through Dykxhoorn et al.'s (2022) prioritised determinants (see *Table 7*).

[79] Main contributors: Timothy Daly and Paola Buedo.

Table 7. An analysis of the intersection between SRM deployment and prioritised determinants from public mental health.

Prioritised determinant	Inaction risk (no SRM deployment)	SRM risk-risk trade-offs for public mental health
Individual Level		
Trauma	Increased exposure to climate disasters (heatwaves, storms).	**Benefit:** May reduce acute trauma by moderating extreme weather. **Trade-offs:** Could introduce new anxieties about technological dependency or side effects.
Income	Economic instability from climate damage (crop failures, infrastructure loss), increasing financial stress.	**Benefit:** May stabilise some climate-sensitive economies (e.g., agriculture). **Trade-offs:** Uneven benefits could deepen disparities (e.g., energy sector job losses).
Employment	Job losses in climate-vulnerable sectors (farming, fisheries, tourism).	**Benefit:** Could protect outdoor/extractive industries. **Trade-offs:** May delay green transition, creating long-term labor market uncertainty.
Family Level		
Early life attachment & parenting	Climate displacement disrupts family stability; parental stress impairs caregiving.	**Benefit:** Potentially reduces forced migration, preserving family cohesion. **Trade-offs:** Parental anxiety about SRM's long-term effects may indirectly strain child wellbeing.
Community Level		
Social support & networks	Climate disasters fracture communities through displacement.	**Benefit:** May prevent breakdown of social ties by reducing climate shocks. **Trade-offs:** Unequal perceptions of SRM could fuel community divisions.

Prioritised determinant	Inaction risk (no SRM deployment)	SRM risk-risk trade-offs for public mental health
Access to health & social care	Systems overwhelmed by climate-linked illnesses (heat stress, infectious diseases).	**Benefit:** Could ease pressure on healthcare systems by reducing some climate impacts. **Trade-offs:** New SRM-linked health concerns (e.g., air quality) could strain services in polar extremes.
Social inclusion & cohesion	Resource scarcity intensifies exclusion of marginalised groups.	**Benefit:** Stabilised climates may reduce conflict over resources. **Trade-offs:** Top-down or market-driven SRM governance could replicate existing power imbalances.
Structural Level		
Displacement	Mass migration from uninhabitable regions, creating refugee crises.	**Benefit:** Might slow displacement by reducing abrupt climate changes. **Trade-offs:** If SRM fails or is halted abruptly ("termination shock"), displacement risks could rapidly resurge.
Inequality & inequity	Climate impacts deepen global and local disparities.	**Benefit:** Could temporarily reduce some climate injustices. **Trade-offs:** Uneven control of SRM may concentrate power with wealthy nations.
Welfare system	Collapse of safety nets under climate-driven demand (disasters, unemployment).	**Benefit:** Potential to reduce acute welfare burdens from climate shocks. **Trade-offs:** SRM research and deployment may divert resources from necessary systemic reforms.

Source for prioritised determinants: Dykxhoorn et al. (2022).

This analysis reveals possible tensions. At the individual level, SRM could mitigate trauma from extreme weather and stabilise income/employment in climate-sensitive sectors, yet its deployment risks reinforcing “techno-solutionism” (Morozov, 2013), which could divert attention from root causes of climate distress and create new anxieties about our dependency to “fix” climate change. Similarly, SRM could reduce family-level disruptions (such as forced migration) and preserve community cohesion, but its socially disruptive potential (Taebi et al., 2023) could exacerbate family, community and (inter)national tensions if governance replicates existing power imbalances. This possibility underlines the importance of good, participatory governance in public mental health

(WFPHA, 2024)[80].

On a more structural level, SRM's capacity to slow displacement and ease burdens on welfare is counterbalanced by its risks of mitigation deterrence ("moral hazard"), potentially delaying systemic reforms to energy and economic systems that drive climate inequities (Andrews et al., 2022). This aligns with concerns about "technomoral" change (Taebi, 2023), that is, SRM could reshape societal norms around climate responsibility, leading people to understand it not as a stopgap complement to mitigation, but the legitimisation of an unsustainable status quo.

Public mental health impacts hinge on whether and how SRM's design and deployment is accepted. These are inevitably shaped by value-laden assumptions (Morozov, 2013). Policy makers can choose to prioritise equity or instead replicate the inequities that worsen climate-related mental health burdens. Participatory governance is required to reduce the risk of SRM becoming a disruptive technology (Hopster, 2021) that addresses symptoms (i.e. acute climate harms) while neglecting determinants like social inclusion and justice, which are concerns found at the heart of public mental health.

2. Perspectives for a public mental health programme

If deployment of SRM were ever implemented, a robust public mental health co-research programme should be established to promote and safeguard public mental health. This programme should prioritise a form of participatory governance and work directly with communities in situations of vulnerability to climate change (Luna, 2019) to co-construct research priorities. This would be a form of what the United Nations Environmental Program (UNEP)'s One Atmosphere (2023) policy document calls "Indoor" social science research. This term is however misleading, because it would require working on the ground with communities.

This approach would be particularly important in regions such as Latin America where:

- Contextual exposure to determinants of ill mental health is high (Buedo & Daly, 2024),
- Vulnerabilities to negative health effects of climate change overlap (Hartinger et al. 2025);
- There are no meaningful governance structures yet in place for SRM (Carabajal et al., 2025).

Participatory research would maximise the exercise of communities' autonomy and ensure that lived experiences of exposure to determinants of mental health shape SRM's development from the outset. Top-down approaches to governance are likely to exacerbate existing mental health vulnerabilities, in a situation in which excluded communities would face the compounded trauma of climate and loss of agency over potential solutions.

As we will argue in the next chapters, a co-produced research agenda would examine how SRM, and its place and priority within the climate response portfolio, intersects with mental health

[80] See chapter 6 and 7.

determinants that matter to people and communities (see Chapter 6). These actions should be guided by the values of public health, such as the World Federation of Public Health Associations (WFPHA) values of equity, justice, and inclusivity as well as those related to SRM (see Chapter 2, section 2.4), ensuring that SRM research centers those most vulnerable to both climate change and its potential technological solutions.

3. Final considerations

If deployment of SRM were ever to take place, public mental health expertise should be embedded into the governance of SRM (research and deployment), from modeling indirect harms to designing interventions to promote and safeguard public mental health. This foundational co-research is important to avoid replicating historical patterns of exploitation, where marginalised groups bear the psychological costs of decisions made without their consent.

The goal for an SRM—public mental health research programme should be a precautionary framework to anticipate the currently unknown risk/benefit profile of a potential SRM deployment and thus stress the need to promote and safeguard public mental health. Investment in technical capacity for SRM should thus be accompanied by investment in co-interventions that aim to promote and safeguard public mental health.

Part III. Ethical SRM governance for a healthy climate future

Chapter 5. Ethical principles for SRM research: human health consequences[81]

1. Introduction

Since 2009, academics, scientific bodies, and non-governmental organizations (NGOs) have attempted to establish systematic governance "principles"[82] for geoengineering or climate intervention in general (see Chapter 2) and for solar radiation management (SRM) in particular, 'from the bottom up' (Brent et al., 2024, p. 948).

The most influential principles for SRM are the Oxford Principles (Rayner et al., 2009, 2013). These principles had a remarkable impact inside and outside of academia (Rayner et al., 2013, p. 4). Nevertheless, they are not the first set of principles:

> "Long before climate geoengineering began to be taken seriously, Dale Jamieson proposed four principles covering the deployment of technologies that could cause "intentional climate change" [Jamieson, 1996]. Another set of principles for geoengineering research, modelled on the Belmont Principles for human subject research have been also proposed (Morrow et al., 2009)"[83].

In a recent article, Brent et al. (2024) synthesize ten governance proposals[84] for solar radiation modification. New proposals are being developed, as in the case of the American Geophysical Union (AGU) principles (Williams et al., 2024).

In this chapter, we will analyse these ethical and governance proposals, and afterwards we will examine whether they address the potential health implications of SRM.

2. Ethical and governance proposals for SRM

Over the past fifteen years, ethical and governance proposals have been put forward to guide SRM. These frameworks provide policymakers with a solid basis for developing domestic instruments to govern SRM research and development (Brent et al., 2024, p. 947). The primary concern is to ensure operationalization of such principles, that is, that these *general* principles be integrated into more formal mechanisms such as institutional research policies and national legislation, and tailored to local and national contexts (see Box 1).

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[81] Main contributor: María Florencia Santi.

[82] As we will see next, some are principles, while others are articles, recommendations, messages, etc. Although it is not accurate to refer to all of them as principles, the literature does so to facilitate presentation (Brent et al., 2024). We will do the same.

[83] Rayner et al. (2013, p. 4).

[84] We will refer to governance proposals following the literature. Although part of them are ethical *and* governance proposals or principles.

Box 1. Summary of key policy insights according to Brent et al. 2024

Key policy insights
Existing informal governance proposals lack specificity, oversight and enforcement, making formal domestic governance necessary for SRM research and development (R&D).
Nevertheless, existing informal proposals provide consistent expectations for SRM governance and can inform domestic law and/or institutional rules for SRM R&D, including overarching objectives, timing and form of governance, and procedural/operational principles.
Domestic policymakers should implement these principles in law to promote accountability and oversight of SRM R&D, and should evaluate how they operate in practice.
The way in which each nation implements these principles will vary and requires multistakeholder consultation, including with neighbouring states to account for diverse perspectives and priorities.

Source: Brent *et al*. (2024, p. 947).

The main priority is to translate general principles into binding instruments, including domestic laws and institutional research ethics processes, especially in countries where SRM R&D is already taking place. Brent et al. (2024) systematically reviewed and categorized the principles in current use demonstrating that there is a high level of commonality between them.

Table 8 presents the core principles and codes that have shaped the governance debate. We also include the recently issued American Geophysical Union (AGU) *Ethical framework principles for climate intervention research* (Williams et al., 2024).

Table 8 . Ethical and governance proposals for geoengineering

Governance proposals	Year	Title	Audience
Oxford Principles[85]	2009 2013	Memorandum on draft principles for the conduct of geoengineering research (2009) & The Oxford Principles (2013)	Researchers
Asilomar Principles[86]	2010	The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques	Researchers
BPC Plan[87]	2011	Task Force on Climate Remediation Research	Domestic policymakers
SRMGI Report[88]	2011	Solar Radiation Management: The governance of research	Researchers
EuTRACE Report[89]	2015	The European Transdisciplinary Assessment of Climate Engineering	Domestic policymakers
Calgary Code[90]	2017	Code of Conduct for Responsible Geoengineering Research	Researchers / Domestic & International policymakers
Tollgate Principles[91]	2018	The Tollgate: Principles for the Governance of Geoengineering	Researchers
FCEA Report[92]	2018	Governing solar radiation management: Academic working group on climate engineering governance	Researchers / Domestic & International policymakers
NASEM[93]	2021	Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance	Domestic policymakers
C2G Report[94]	2022	Solar Radiation Modification: Governance Gaps and Challenges	Researchers / Domestic & International policymakers
AGU[95]	2024	Ethical framework principles for climate intervention research	Researchers / Domestic & International policymakers

Source: Adapted from Brent et al. (2024).

The analysis by Brent et al. (2024) offers a detailed review of the governance proposals.

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85 Rayner et al. (2009, 2013).
86 Asilomar Scientific Organizing Committee (2010).
87 Bipartisan Policy Center (2011).
88 Solar Radiation Management Governance Initiative (2011).
89 Schäfer et al. (2015).
90 Hubert (2017).
91 Gardiner & Fragnière (2018).
92 FCEA stands for Forum for Climate Engineering Assessment. See Chhetri et al. (2018).
93 Report – NASEM (2021).
94 Reynolds et al. (2022).
95 Williams et al. (2024).

Seven of these frameworks include CDR and SRM, while four focus exclusively on SRM[96]. Across these documents, some address research activities (such as the Asilomar Principles), others potential deployment (AGU). The principles are aimed at researchers and domestic and/or international policymakers. The majority of the principles were developed by a multi-disciplinary team and engaged with different stakeholders and civil society. The governance proposals were developed by academics, scientific bodies, and non-governmental organizations (NGOs) representing diverse perspectives and disciplines.

These documents differ in scope, length, and intended audience, but converge on a shared objective: establishing a foundation for conducting responsible research, enhancing potential benefits, reducing associated risks, and fostering meaningful public engagement. Importantly, none of these proposals for governance is based on the assumption that SRM should replace mitigation or adaptation efforts to address climate change.

Taken together, the proposals delineate various forms of normative statements—such as principles, codes, articles, messages, objectives, and recommendations—designed to guide the research, development, and potential deployment of geoengineering. Table 9 presents each document alongside its corresponding statement type and the principles or recommendations advanced[97].

Table 9. Overview of ethical and governance principles for geoengineering

Governance proposals / Type of statement	Content
Oxford Principles *Principles*	1. Geoengineering to be regulated as a public good. 2. Public participation in geoengineering decision-making. 3. Disclosure of geoengineering research and open publication of results. 4. Independent assessment of impacts. 5. Governance before deployment[98].
Asilomar Principles *Recommendations*	1. Promoting Collective Benefit. 2. Establishing Responsibility and Liability. 3. Open and Cooperative Research. 4. Iterative Evaluation and Assessment. 5. Public Involvement and Consent[99].
BPC Plan	1. …[C]limate remediation research. The fundamental purpose of the research should be to protect the public and the environment from both the potential

[96] SRMGI, FCEA, NASEM and C2G reports refer only to SRM.

[97] When proposals are articulated as brief principles, these are reproduced in full; when their length exceeds the table's constraints, they are summarized or included in a footnote. In exceptional cases, readers are directed to the original source text.

[98] Rayner et al. (2009, 2013).

[99] Asilomar Scientific Organizing Committee (2010, pp. 17-24).

Principles	impacts of climate change and from the potentially damaging impacts of climate remediation technologies. 2. Testing and deploying climate remediation technologies (…). 3. Oversight issues for research programs (…). 4. Importance of Transparency (…). 5. International coordination (…). 6. Adaptive management (…)[100].
SRMGI Report *Messages*	1. Nothing now known about SRM provides justification for reducing efforts to mitigate climate change (…). 2. Research into SRM methods for responding to climate change presents some special potential risks (…). 3. There are many uncertainties concerning the feasibility, advantages and disadvantages of SRM methods, and without research it will be very hard to assess these. 4. Research may generate its own momentum and create a constituency in favour of large-scale research and even deployment (…). 5. A moratorium on all SRM-related research would be difficult if not impossible to enforce. 6. Some medium and large-scale research may be risky, and is likely to need appropriate regulation. 7. Considering deployment of SRM techniques would be inappropriate without (…) adequate resolution of uncertainties concerning the feasibility, advantages and disadvantages (…). 8. The development of effective governance arrangements for potentially risky research (including that on SRM) (…) requires wide debate and deliberation (…). 9. International conversations about the governance of SRM should be continued and progressively broadened to include representatives of more countries (…)[101].
EuTRACE Report[102] *Principles*	1. The minimisation of harm. 2. The precautionary principle. 3. The principle of transparency. 4. The principle of international cooperation.
Calgary Code[103]	• [Proper] use of Geoengineering[104].

[100] Bipartisan Policy Center (2011, pp. 13-14).

[101] Solar Radiation Management Governance Initiative (2011, pp. 10-11).

[102] They argue that some of the techniques must be understood as public goods. Based on these principles they proposed different strategies to guide climate engineering approaches: Early public engagement, independent assessment, disclosure mechanisms and transparency, international codes of conduct, responsible innovation and anticipatory governance. Schäfer et al. (2015, pp. 109-111).

[103] This document is a Code of conduct. They divide the code into four parts: A) nature, scope and objective; B) general principles; C) guidance on geoengineering research and D) interpretation and application of this code of conduct. The articles mentioned correspond to part C. Hubert (2017, pp. 5-10).

[104] This article points out: 1. (...) no geoengineering activities should take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of environmental and other effects. 2. An exception to paragraph 1 can be made for responsible geoengineering research conducted in accordance with all applicable laws and regulations and on the basis of the guidance in this Code of Conduct. 3. Geoengineering should not be promoted or used as a substitute for measures that anticipate, prevent or minimise the causes of climate change, especially through effective measures to reduce greenhouse gas emissions, and to minimise the adverse effects of climate change through the adoption of suitable adaptation measures (Hubert, 2017, p. 6).

Articles	• Cooperation on Geoengineering Research. • Principles and Practices for Responsible Geoengineering Research. • Assessment of Outdoor Experiments on Geoengineering. • Public Participation. • Post-Project Monitoring of Outdoor Experiments on Geoengineering. • Access to Information.
Tollgate Principles *Principles*	1. Geoengineering should be administered by or on behalf of the global, intergenerational and ecological public (…). 2. Geoengineering decision-making (e.g. authorizing research programs, large-scale field trials, deployment) should be done by bodies acting on behalf of (…) the global, intergenerational and ecological public (…). 3. Decisions about geoengineering research activities should be made only after proper notification and consultation of those materially affected and their appropriate representatives, and after due consideration of their self-declared interests and values. 4. Geoengineering policy should be organized so as to facilitate reliability, trust and accountability across nations, generations and species. 5. Ethical Accountability: robust governance systems (…) are increasingly needed and ethically necessary at each stage from advanced research to deployment. 7. For a geoengineering technique to be policy relevant, ethically defensible forms of it must be reasonably predictable on the relevant timeframe and in relation to the threat being addressed[105]. 8. Protection: climate policies that include geoengineering schemes should be socially and ecologically preferable to other available climate policies, and focus on protecting basic ethical interests and concerns (e.g. human rights, capabilities, fundamental ecological values). 9. Geoengineering policy should respect general ethical norms that are well-founded and salient to global environmental policy (e.g. justice, autonomy, beneficence). 10. Respecting Ecological Norms[106].
FCEA Report *Objectives*	1. Keep mitigation and adaptation first. 2. Thoroughly and transparently evaluate risks, burdens, and benefits. 3. Enable responsible knowledge creation. 4. Ensure robust governance before any consideration of deployment[107].
NASEM *Recommendations*	Based on NRC (2015) recommendations[108].
C2G Report *N/I*	Based on several principles, this document focuses on challenges and gaps in SRM governance: • Facilitate responsible research. • Guide outdoor experiments and engage with the global public[109].
AGU	1. Responsible Research.

[105] Principles 6 and 7 are practically the same, so 6 is omitted.
[106] Gardiner & Fragnière (2018, pp. 152-166).
[107] Chhetri et al. (2018, p. 17-21).
[108] The document makes numerous recommendations that exceed the scope of this table. See NASEM (2021).
[109] Reynolds et al. (2022).

Principles	2. Holistic Climate Justice. 3. Inclusive Public Participation. 4. Transparency. 5. Informed Governance[110].

The above table has values that are **substantive**. That is, they propose high-level principles that advocate compliance with ethical standards of great significance and scope: do no harm, promote potential benefits and comply with intergenerational and environmental justice. For instance:

- "Geoengineering to be regulated as a public good" (1st Oxford principle).
- "Geoengineering should be administered by or on behalf of the global, intergenerational and ecological public" (1st Tollgate principle).
- "Thoroughly and transparently evaluate risks, burdens, and benefits" (2nd FCEA Objective).
- "Facilitate responsible research" (C2G and 1st AGU principle).
- [Promote] "Holistic Climate Justice" (2nd AGU principle).

Many others are **procedural**, that is, they indicate how these technologies should be implemented, the safeguards that should be considered, the prior agreements that are required, and the individuals and groups that should be consulted in advance. For example:

- "Governance before deployment" (2nd Oxford principle).
- "Public Involvement and Consent" (5th Asilomar recommendation).
- "Importance of Transparency" (4th BPC Plan principle).
- [Enact] "Post-Project Monitoring of Outdoor Experiments on Geoengineering" (Calgary Code article).

The importance of **public engagement or participation** is highlighted in most governance proposals. Two of the Tollgate's principles are dedicated to this issue:

> "2nd Tollgate Principle (Authorization): Geoengineering decision-making (e.g. authorizing research programs, large-scale field trials, deployment) should be done by bodies acting on behalf of (e.g. representing) the global, intergenerational and ecological public, with appropriate authority and in accordance with suitably strong ethical norms (e.g. justice, political legitimacy).
>
> 3rd Tollgate Principle (Consultation): Decisions about geoengineering research activities should be made only after proper notification and consultation of those materially affected and their appropriate representatives, and after due consideration of their self-declared interests and values (2nd and 3rd Tollgate principles)" (Gardiner & Fragnière, 2018, pp. 166-167).

Other proposals also advocate for public involvement or participation:

- "Public participation in geoengineering decision-making" (2nd Oxford principle).

[110] Williams et al. (2024, pp. 10-13).

- "Public Involvement and Consent" (5th Asilomar principle).
- "The development of effective governance arrangements for potentially risky research (including that on SRM) (…) requires wide debate and deliberation" (…). (8th message, SRMGI Report).
- "Inclusive Public Participation" (3rd AGU principle).

This last principle emphasizes the importance of public participation and also highlights its challenges:

> "Research and the decision to pursue it should incorporate inclusive and equitable processes for public participation and include assessment of the communities that may be impacted and thus should be participating. While building inclusive participatory processes is complex, research should be guided by values of proportionality, openness, equitable participation, and cooperative engagement. This engagement should begin by including the relevant communities in discussion of the purposes and design of research. Researchers and policymakers should consider broader inclusion, making efforts to consider perspectives of those communities that are unsure whether they are or will be impacted, and those who are unable to contribute to the deliberation, such as future generations and the plant and animal ecosystems involved" (Williams et al. 2024, p. 13).

As participation and engagement is so salient in all these documents we will devote the next chapter to explore this issue in depth.

The governance proposals also mention the importance of **international cooperation and coordination**:

- "International coordination" (5th BPC Plan).
- "International conversations about the governance of SRM should be continued and progressively broadened to include representatives of more countries" (9th message, SRMGI Report).
- "The principle of international cooperation" (4th principle, EuTRACE Report).

As also pointed out in the Introduction of this Report, regarding SRM this international coordination does not exist and should be built. This represents a major challenge. Our last chapter will explore some ethical considerations in this area. However these documents represent shared expectations regarding the objectives and timing of SRM governance. They reached agreement on several procedural rules intended to advance responsible research (Royal Society, 2025, p. 92).

Again, we should outline that these governance proposals have an over-representation of members of the Organization for Economic Cooperation and Development (OECD) among their authors, while the Global South remains markedly underrepresented (Brent et al., 2024, pp. 949–953). According to Brent, this imbalance results in a substantial representational gap across most principles and guidelines:

> "[SRM documents] were developed by participants in the Global North. They will therefore require adjustment and augmentation to suit the specific governance needs of SRM R&D in individual jurisdictions. Indeed, the process of translating these principles into

formal rules may trigger multistakeholder processes at the domestic level, including broader community engagement, deliberation and consensus-building regarding SRM governance" (Brent et al., 2024, p. 948, edited).

Addressing this representational gap is essential to ensure that the perspectives, priorities, and concerns of populations in the Global South meaningfully inform emerging SRM governance frameworks.

Up to this point, we have analysed the ethical and governance principles and guidelines for SRM, identifying both their strengths and their limitations. The following section revisits these documents to assess whether they explicitly engage with the potential impacts of SRM technologies on human health. This assessment is especially crucial given the need to anticipate possible health consequences for all populations, but particularly for the Global South, who are likely to experience disproportionate vulnerabilities.

3. SRM and its consequences on human health

The governance proposals have in common the main "aim to promote responsible research, minimising risks while also realizing potential climate benefits" (Royal Society, 2025, p. 93; Brent et al., 2024, p. 486). Although most of the governance proposals refer to *risk minimization*, *risk assessment*, or the *promotion of benefits*, there are few explicit and direct references to the potential impact of these technologies on human health.

In Table 10 we analysed the ethics and governance principles in order to identify direct or indirect references to the potential adverse health consequences related to SRM technologies.

Table 10. Governance proposals and health consequences

Governance proposals	Health consequences
Oxford Principles	Indirectly: "[T]he principle of independent impact assessment acknowledges that scientists have responsibilities to ensure that carrying out their research **does not negligently harm persons or a local environment**"[111].
Asilomar Principles	Indirectly: "Assessing potential intended and unintended consequences, **impacts**, and **risks** will be critical to providing governments and the public with the information and confidence needed to evaluate the potential for climate engineering to be implemented as a complement to mitigation and adaptation"[112].
BPC Plan	Indirectly: "The fundamental purpose of the research should be to protect **the public** and the **environment** from both the **potential impacts** of climate change and from the potentially **damaging impacts** of climate remediation technologies"[113].
SRMGI Report	Indirectly: "Research into SRM methods for responding to climate change presents some special **potential risks**"[114].

[111] Rayner et al. (2013, p. 32).
[112] Asilomar Scientific Organizing Committee (2010, p. 21).
[113] Bipartisan Policy Center (2011, p. 13).
[114] Solar Radiation Management Governance Initiative (2011, p. 9).

EuTRACE Report	Indirectly: "The **minimisation of harm**: The risk of individuals being exposed to harm from climate engineering, the number of people exposed to risks, and the magnitude of the potential harm should all be kept as low as possible, and serious and irreversible harm should be avoided"[115].
Calgary Code	Indirectly: "All appropriate and effective measures should be taken to prevent and minimise the **risk of harm** from outdoor experiments on geoengineering and to maximise the benefits of such experiments"[116].
Tollgate Principles	Indirectly: "Protection: climate policies that include geoengineering schemes should (…) focus on **protecting basic ethical interests and concerns (e.g. human rights, capabilities, fundamental ecological values)**[117].
FCEA Report	They refer to **"health safety"** and **"human health impact".** Although their main focus is Environmental Impact, this assessment presumably includes health impacts.
NASEM	Directly: "SG [solar geoengineering] (…) raises concerns about **new risks, uncertainties, and unintended impacts on natural ecosystems, agriculture, human healt**h, and other critical areas of concern for society" [118].
C2G Report	Directly: they do refer to **human health related to possible effects of SAI**[119].
AGU	Indirectly: "Risk assessment must consider the **direct impacts** of the activity concerned as well as the **potential physical, environmental, and social implications** if that activity were scaled"[120].

The excerpts presented in Table 10 illustrate the ways in which these documents refer to the risks associated with SRM technologies, including those that may affect human health. As shown, although most frameworks acknowledge risks, references to potential health consequences are generally indirect and only implicitly addressed. Only three include explicit mentions of health consequences. NASEM Recommendations directly warns:

> "SG [solar geoengineering] (…) raises concerns about new risks, uncertainties, and unintended impacts on natural ecosystems, agriculture, human health, and other critical areas of concern for society"[121]. [Later adds] "Any country engaged in SG research should prepare programmatic assessments that collectively assess the health, environmental, and social impacts of all SG activities that it sponsors or approves and any SG research program that it adopts" (NASEM, 2021, p. 172).

The FCEA Report mentions "health safety" and "human health impact". Nevertheless they primary focus is Environmental Impact Assessment that presumably includes health impacts:

> "Develop best practices for risk and impact assessments. Who should take action?

[115] Schäfer et al. (2015, p. 109).
[116] Hubert (2017, p. 7).
[117] Gardiner & Fragnière (2018, p. 163).
[118] NASEM (2021, p. 4).
[119] Reynolds et al. (2022, p. 24).
[120] Williams et al. (2024, p. 11).
[121] NASEM (2021, p. 4).

National level governments, risk assessment and Environmental Impact Assessment (EIA) experts, and SRM researchers National level governments, risk assessment and EIA experts, and SRM researchers should work together to expand risk assessment and EIA procedures and protocols so that they can provide precautionary evaluation of potential direct social and environmental harms, as well as enable public notification and consultation, for SRM experiments" (Chhetri et al., 2018, p. 44).

Finally, C2G refers to possible impacts of SAI on human health[122]. It may therefore be concluded that most documents address the health implications of these technologies only indirectly, through general references to potential risks and associated effects and impacts. For instance (see AGU Principles and also the BPC Plan).

"The fundamental purpose of the research should be to protect the public and the environment from both the potential impacts of climate change and from the potentially damaging impacts of climate remediation technologies" (Bipartisan Policy Center, 2011, p. 13).

These findings reveal a gap in the explicit consideration of human health within existing SRM governance proposals.

4. Final considerations

In this chapter we review existing ethical and governance frameworks for SRM research and highlight their relevance for addressing potential human health consequences. While, on one hand, the documents consistently emphasize responsible research practices, risk management, and public engagement, explicit attention to the potential health consequences of SRM remains limited. This underscores the importance of incorporating more systematic evaluations of health-related risks into future governance frameworks, ensuring that emerging guidance aligns with broader commitments to safeguarding human well-being especially in the Global South. On the other hand, it should be underscored that these documents are mostly directed to institutional or domestic operationalization (even if some of them may have an international ambition). The international cooperation and coordination they point to is very vague and underdeveloped.

[122] Reynolds et al. (2022, p. 24).

Chapter 6. Public engagement at the intersection of SRM-health issues[123]

Introduction

The implementation of Solar Radiation Modification (SRM), if it ever happens, will not depend solely on technological readiness, but also, and more fundamentally, on the surrounding social and political context (Carvalho & Riquito, 2022; Fritz et al., 2024). In democratic systems, public opinion plays a crucial role: society can both legitimize or reject scientific research and experimentation because of its expected outcomes —as said in the Postface—, while also shaping governance frameworks through different types of practices and demands.

Currently, the public is mostly unfamiliar with these sets of technologies although debates are gradually emerging as climate risks intensify and political measures to reduce emissions advance more slowly than expected. In this context governance debates and their implications for society are being led primarily by Global North countries (Baum et al., 2024), particularly Europe and the United States, while the voices of the Global South remain largely marginalized (Rahman et al., 2018; Jinnah & Dove, 2025) as we have also shown in chapter's 3 bibliographical review, regarding authors and funding. Moreover, the low levels of familiarity with SRM pose additional challenges that require a holistic understanding of public perception within broader contexts of values and perspectives (Low et al., 2024). For this reason, as mentioned by several documents presented in chapter 5, public engagement becomes critical for enhancing transparency in decision-making, ensuring driving procedures of pluralism, inclusion and climate justice.

As we said in the previous chapter, ensuring the operationalization of governance principles, in terms of integrating them into formal mechanisms, is a priority. But in that process, improving participation and engagement should be treated as a standard operating procedure for responsible research and non-research experimentation (Jasanoff, 2003). Opening up deliberative spaces among laypeople, stakeholders, government representatives and experts is essential to ensure a better balance of perspectives and values. Warranting broad participation of Global South voices is key to reach intercultural and inclusive governance debates (Carabajal et al., 2025). In this context, the health dimension can play a key role in these debates, as it is at the forefront of the impacts of climate change.

1.1. Challenges for public engagement

Public engagement means different ways to engage the public with these emerging technologies. Approaches vary from notification, consultations and prior informed consent of potentially affected communities. How to ensure a meaningful public engagement process is crucial. The effects of any SRM technology are uncertain, unequal and global, and the perceived legitimacy of the participation will affect the legitimacy of any type of decision, regardless of the legislative procedure it may have undergone. The global dimension of this technology is a challenge per se, as at present there are no global procedures to ensure that all the voices are equally heard. As a

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contested technology, the debate ranges from total opposition to research on the topic (Biermann et al., 2022), with a middle term position of strong advocacy for advancing scientific knowledge that can inform decision-making (Jamieson, 1996; Parson et al., 2024, and most authoritative reports on SRM, including COMEST, 2023; EGE, 2024; Royal Society, 2025), to another extreme of direct action (Make Sunsets, in Carabajal et al., 2025) (see Chapter 2, section 2.4). Between these extremes, and even within the middle term, lies a spectrum of more nuanced positions, reflecting the complexity of the issue. As outlined in Chapter 1, common concerns include the so-called "moral hazard" argument (mitigation deterrence), as well as the potential unintended consequences, risks posed by both climate change and SRM itself, and geopolitical tensions. At the heart of these concerns lie key governance questions: who would control the "global thermostat", who would have the authority to make final decisions about deployment, and who would gain or lose (see Postface).

Some scholars argue that a governance framework grounded in deep and broad public engagement—one that genuinely considers "what the people want"—will result in socially accepted climate policies (Perlaviciute, 2022). However, when it comes to emerging and controversial technologies, assumptions about who "the public" is, what they want, and who should be involved, cannot be taken for granted. The global scope of SRM challenges conventional understandings of "the public" in participatory governance. And perhaps most importantly, how can we understand and conceptualize different national and institutional civic epistemologies, and address their implications for global debates on scientific governance (Jasanoff, 2005; Macnaghten & Guivant, 2011). Decisions about technologies with planetary implications cannot be confined to national boundaries, as awareness and capacity to engage vary drastically across regions (Mercado et al., 2023). A national perspective would also not address the unequal potential impacts of SRM, therefore, public engagement done properly in one country or region do not reflect the perspectives of others places and do not provide any authorization if the impacts are globally.

In addition, public engagement must confront questions of representation, equity, and justice, ensuring that those with many vulnerabilities to climate impacts, often in the Global South, are not marginalized from deliberation. Addressing inclusion across scales implies not only broadening participation geographically but also rethinking whose voices count in shaping global climate interventions. All those potentially affected should have a voice in the discussion; yet, determining how to ensure inclusive, and informed participation remains a complex challenge. In this sense, we advocate for a meaningful engagement, which goes beyond consultations, as it is intimately related to anticipatory governance[124]. The anticipatory perspective acknowledges the uncertainty and indetermination of the future that will be shaped by political, social values, concerns and perspectives.

1.2. How should we approach public engagement: rethinking the science–public relationship

[124] The latter concept involves building the ability across society to foresee, discuss, and shape the evolution of emerging technologies informed by knowledge, ensuring that their direction can be managed before it becomes irreversible (EEA Report, 2024; Guston, 2014).

The international literature identifies two polar models in proposals for risk governance, constructed from the intersection of two axes: one referring to conceptions of the public and the other to conceptions of science (Joly, 2001; Guivant, 2005). One is the **standard model**, in which differences in risk perception between experts and laypeople are attributed to the latter's irrational attitudes, cognitive biases, difficulties reasoning probabilistically, aversion to innovation and risk, etc. Within what is generally identified as the positivist model, a clear separation is established between facts and values. Scientists are attributed an objective and neutral view of facts, while laypeople formulate their opinions from a subjective standpoint. In this model science is conceived as a practice independent of political, economic, or social influences. Trust in institutions responsible for risk management is central to this model. Therefore, it is considered unnecessary to make problems or doubts visible, so as to avoid panic among the lay public. The reduction of the gap between expert and lay perceptions is achieved through information dissemination and education. Risk communication thus assumes a prominent role and occurs in a linear direction, in accordance with what risk theories call the deficit model: experts communicate knowledge to laypeople in order to prevent them from remaining ignorant and irrational. This model is mostly considered as outdated and does not fit with controversial technologies like SRM.

The other pole, that of the **non-positivist view of science**, distinguishes itself by questioning what conception of science guides expert work. Here we are in the territory of the new sociology of science and social studies of science. "Science is considered as offering a framework that is unavoidably social as well as technical since in public domains scientific knowledge embodies implicit models or assumptions about the social world" (Irwin & Wynne, 1996, p. 2-3).

Rather than asking whether an innovation with uncertain consequences is accepted or not, this approach poses more open questions, such as: What problem does this technical solution address? Are there alternatives? Who benefits from this technology? Socio-technical controversies are not seen as obstacles but as opportunities to explore possible alternatives. The collective interest is not assumed to be self-evident but rather the product of negotiation, alliances, and social conflicts. Technology is not a fatality nor merely a source of progress but an instrument for building a shared world.

Because there are limits to determining standards for potential risks solely through scientific knowledge, it is not only necessary to make decisions but also to reestablish the rules and bases on which such decisions are made—opening dialogue and decision-making processes and recognizing ambiguity, ambivalence, and social conflict as inevitable. To achieve this, new negotiation spaces are needed to de-monopolise expert knowledge, accepting that lay knowledge is not irrational. Value judgments are present in all stages of the risk management process, especially those involving serious consequences (invisible, long-term, and irreversible) as outlined by Beck (1999). These two visions also divide experts themselves.

1.3. Different forms of public engagement

Public participation can be defined "as a practice of consulting and involving members of the public in the agenda-setting, decision-making, and policy-forming activities of organizations or institutions responsible for policy development" (Rowe and Frewer, 2004, p. 512). At a basic level, involvement may merely entail the communication of information to the public, corresponding to the assumptions of the standard model. At a more complete level, various methods can be identified (including dialogue and two-way communication), such as consultation exercises, focus groups, and questionnaires, with varying degrees of formalization (Guivant, 2005).

As Rowe and Frewer (2000) explain, the reasons for increasing interest in public participation in science policy are diverse but can mainly be attributed to both the recognition of basic human rights in a democracy and the pragmatic recognition of the importance of avoiding unpopular policies. Therefore, establishing procedures could also avoid capturing interest in detriment of public good (EGE, 2024). The benefit of public involvement is that it increases public trust in decision-making processes and information sharing. No public engagement method can be completely satisfactory; choices depend on different factors that may change at various stages of the decision-making process, and these must be evaluated and monitored both by sponsors and by the responsible authorities. One dilemma concerns how to assess the efficiency of each method in different contexts and situations. There is still little systematization of this issue in the academic literature, which remains primarily oriented toward procedural aspects of implementation rather than on substantive outcomes (Rowe and Frewer, 2000; Bellamy et al., 2017).

It is also necessary to avoid applying participatory methods to any public issue indiscriminately. Their main contribution concerns decisions on value-laden and highly controversial topics, rather than technical issues where there may be mere disagreement (Funtowicz & Ravetz, 1993; Funtowicz & Hidalgo, 2008). In this respect, it is highly relevant for SRM. But here a fundamental problem emerges: from the standpoint of the standard model of science, values are excluded as a possible influence on scientific analysis. Only when one adopts the assumptions of a non-positivist model of science are values recognized as the basis of negotiation among social actors with differing interests. From this perspective, citizen groups must be respected as having independent positions. This implies, on the one hand, reducing the often-questioned role and influence of industry. But it also implies another relevant and controversial aspect for SRM: the control of NGO participation (Macnaghten and Guivant, 2020).[125] The need arises to reflect on how, in what forms, and at which stages public participation strategies should be created within decision-making processes concerning uncertain risks. This, of course, must be done without falling into the naïve assumption that public participation automatically ensures transparency or dialogical democracy (Callon et al., 2001), and without overlooking the necessity of long-term institutional commitment from authorities to conduct these processes impartially—creating spaces where

[125] McGregor (2003, as cited in Guivant, 2005 p. 55) describes an interesting initiative by Health Canada to learn from citizen groups in other countries and how they can be implemented with significant levels of transparency, raises some provocative questions: "What does it mean that those representing the voice of consumers at the policy table do not put as much weight on educating the public as they do on making it easier to get a seat at the table? What does it mean that these representatives seem to be more concerned with making sure the government lets them have a seat at the table than they are with making recommendations on how to be sure they have influence at the policy table? Does their strong focus on improving the process so that it is more visible, inclusive, accountable and accessible preclude their ability to focus on advocating public education about health issues? Would not a more informed public make their 'job' easier relative to influencing the policy process for food and health product review?".

diverse positions on the issue can be openly expressed and circulated. At this point, another challenge emerged concerning the level of trust not only of the authorities but also the process itself to effectively develop policies that reflect the outcomes of the participatory processes.

1.4. No "one-size-fits-all" approaches to inclusive deliberation on SRM

There is no one-size-fits-all approach to inclusive deliberation on SRM. At present, there is no recipe or technique that ensures a successful participatory and inclusive process. The design and outcomes of such efforts will depend on multiple factors, ranging from technical to political. On the technical side, considerations include the specific technologies involved, whether they have local or global implications, and the stage of the research process in the life cycle of the SRM intervention—whether it entails indoor activities such as modelling and simulations, or outdoor experimentation, such as small-scale field trials (see Chapter 2, section 2.3, and Annex Chapter 2). Moreover, these complexities are compounded by the fact that there is little experience of conducting participatory processes for initiatives that could have global impacts (Guivant & Macnaghten, 2011).

Operationalizing engagement requires more than inviting participation. It demands recognition of multiple knowledge systems. At present, where scientific authority is contested, effective engagement depends on valuing diverse epistemologies, including local, indigenous, and experiential forms of understanding and living (Jasanoff, 2003). As argued below, this shift toward knowledge pluralism challenges technocratic models of SRM governance that prioritize expert authority over societal learning. Integrating plural expertise and cross-sector dialogue can enhance not only legitimacy but also the epistemic robustness of decisions, ensuring that social, ethical, and cultural dimensions of risk are considered alongside technical ones.

SRM sits at the intersection of high uncertainty, ethical controversy, and global risk. Public engagement, therefore, cannot be treated as a tool for consensus-building alone but must be understood as a space for ethical reflection and contestation (Bellamy et al., 2016). In contexts of radical uncertainty, deliberation should acknowledge disagreement, plural values, and the moral implications of "technological fixes". Engagement practices sensitive to power relations and moral pluralism are essential for developing a responsible innovation framework that allows democratic scrutiny of research trajectories and governance pathways.

1.5. Collaborative approaches for transformative science in SRM landscapes

SRM research necessarily depends on interdisciplinary work if it is to consider the various aspects of the discussions surrounding the topic and anticipate its governance and the social, cultural and political are key components[126]. Social science perspectives are essential for understanding how the general public perceive these emerging technologies and the values and ethical concerns that influence their opinions[127].

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[126] Currently, there is a significant imbalance in the funding and the number of research groups working on this topic from the natural sciences compared to the social sciences (Heyward & Rayner, 2013), that is equivalent with the more general research on climate change (Guivant & Fromer, 2023).

[127] In particular, it is important to recognize how disciplines such as anthropology, environmental sociology, and the arts

Despite the consensus on the need for interdisciplinarity, there are numerous problems for its implementation that can be extended to the research on SRM. In addition to the more explicit ones, such as lack of sufficient resources and institutional limitations, there are more subtle obstacles, especially in the cognitive and emotional spheres. Members of interdisciplinary teams tend to reproduce their tacit cognitions and are subject to what Kumar & Chakrabarti (2012) called "bounded awareness", a concept that refers to the difficulty of recognizing one's own lack of knowledge or the importance of the contribution of other areas. As has already been extensively demonstrated by social studies of science, research processes are permeated by implicit assumptions, for example, about the social uses of research/technology, about the conditions under which it will be implemented, by which social and economic actors and with what objectives. Interdisciplinary work in SRM is urgently demanding even more a reflective dynamic on such assumptions to overcome practices crystallized in institutions and research practice (Guivant & Fromer, 2023).

Addressing complex and emerging technologies will also need trans-disciplinary approaches, as the academic voices are not the only ones to think about. Different stakeholders and community members should also be involved from an early stage of the research process to define research agendas and priorities. Transformative approaches to science and society take time, human and financial resources, and require a long standing horizon in order to build a shared understanding of multidimensional and complex topics, the development of a mutual learning community and a common language. Moreover, the development of personal skills and abilities is also relevant to address the challenges of these approaches. Research on SRM from an inter-trans/disciplinary perspective could bridge the pointed gaps and involve citizens in debates around its governance regimes. As the stakes are high and opinions are contested, it is essential to address public perceptions of SRM from the outset of the discussions (Stilgoe, 2015; Buck, 2018).

2. Public Perception studies on SRM

At the international level, research on **public perceptions of SRM** remains limited. As already said, existing studies are mostly quantitative and reflect mostly perspectives from Global North countries. However, as the field continues to advance, both quantitative and qualitative analyses are becoming more prominent.

Based on a bibliographic corpus analysis on public perception, it is possible to draw some statements that are commonly presented in different studies:

a) The “lay” public has little familiarity with these issues (Burns et al., 2016; Rosenthal et al., 2023; Buck et al., 2025).

can contribute—through their historical perspectives and holistic approaches to human groups and social relations (Barnes et al., 2013)—to reflections on governance framed by climate and environmental justice, linking the local implications of SRM to its potential global-scale effects.

b) The higher the level of education or access to information on climate change, the greater the degree of acceptance of solar geoengineering research and/or implementation (Burns et al., 2016; Rosenthal et al., 2023; Low et al., 2024; Buck et al., 2025).

c) The frameworks used to present and explain solar geoengineering influence the responses provided by those consulted (Corner & Pidgeon, 2015; Burns et al., 2016).

d) There is a higher level of acceptance of research than of large scale deployment (Sugiyama et al., 2016; Mercer, Keith & Sharp, 2011), and a higher degree of approval for laboratory experimentation than for field experimentation (Merk et al, 2015), as well as for experimentation at the regional level than at the local level —the 'Not In My Backyard' stance— (Rosenthal et al., 2023).

e) There is a relation between the openness to consider geoengineering with feelings of climate urgency, low levels of awareness, frustration over the insufficient civic and political action regarding climate change, and a higher perception of harm or having directly experienced the consequences of climate change (Fritz et al., 2024). Some articles also argue that respondents from countries in the Global South seem to be more inclined to consider solar geoengineering as a viable option yet there is a high diversity of perceptual opinions around SRM research, governance, and potential acceptability within the global south, too. (Sugiyama et al., 2016; Low et al., 2024; Baum et al., 2024; Hussain et al., 2024).

f) Another interesting aspect that has previously been cited in the literature (Mercer, Keith & Sharp, 2011) but according to Buck et al (2025) is reappearing with greater force, is the presence of conspiracy theories among the responses collected.

g) There is a lack of a specific perspective on the opinions of indigenous peoples (Whyte, 2012), and the existence of literature that focuses specifically on the perception of "expert" groups (Mercer, 2014; Dannenberg & Zitzelsberger, 2019; Baum, Low & Sovacool, 2022).

This brief description reconstructs some of the key arguments shaping the current debate on public perceptions of SRM.

At present, a small number of research teams are conducting public perception studies focused on the Latin American region, funded by the Degrees Initiative and the Advanced Research and Invention Agency (ARIA) , the latter hosted by the Inter-American Institute for Global Change Research (IAI). These projects aim to assess how SRM research is perceived in the LAC region, thereby contributing to the broader understanding of public engagement and attitudes toward climate intervention strategies.

3. Health impacts as a key entry point to SRM deliberations

Health impacts, for example, could play a key role in SRM governance from an early-stage. Public engagement with health professionals and the public can help bridge the gap between science and society. They can act as trusted and legitimate intermediaries between technical researchers and the general public, ensuring that health concerns are accurately represented in discussions[128].

Public health strategies and communication might work by weighing risks and constructing meanings that are close to the patient and the communities they work with, involving them with prevention or health promotion campaigns. Public health alliances and collaborative partnerships could provide a foundation for public engagement with SRM, building on the sector's established and trusted approaches.

Incorporating health dimensions with a social and environmental justice perspective could lead to prioritizing the persons with vulnerabilities who suffer the most from the impacts of climate extreme events and climate-related risks, particularly the shifts in temperature and precipitation. Climate change amplifies existing health threats and creates new and potential challenges. So, weighing the risks of climate change impacts versus the risks of SRM in this sector is likely to be a key entry point to discuss potential trade offs, co-benefits and countervailing risks. In this sense, it is interesting to note how the risk-risk analysis is usually brought in research about public perception on SRM.

Health has always worked with narratives focusing on prevention, care or well-being which can also be useful to engage with those concerns related to the perception of personal and community risks. While the technical aspects of SRM may seem distant or abstract, people are more likely to connect with concrete issues such as its implications of heat stress for human health, the impacts of floods and the spread of vector-borne diseases such as malaria, and broader climate-related health risks. Framing SRM in relation to potential benefits and risks to public health makes the debate more immediate, tangible, and directly connected to people's daily lives.

4. Final considerations

Institutionalizing engagement in SRM governance means developing procedures, accountability frameworks, and iterative mutual learning approaches that go beyond symbolic consultation. As a contested topic, establishing normative, procedural ethics guidelines could create the necessary safeguards to avoid groups of interest to capture these public engagement mechanisms, including industry, research, academic groups, for-profit enterprises and environmental activists. Without such integration, engagement risks remaining rhetorical, a procedural checkbox rather than a transformative practice shaping the future of climate governance.

It is essential to ensure that equity, diversity, and inclusion (EDI) strategies are embedded as cross-cutting measures in the participation of research teams, stakeholders, and civil society from the Global South. Countries in this region—often more vulnerable to the impacts of climate change—are also more likely to experience the potential adverse effects of SRM deployment. Consequently, several authors argue that they should play a leading role in global discussions on

[128] See Chapter 3 where the current state of the literature on SRM and its impact on human health is detailed.

these issues (Aldy et al., 2021). However, researchers from the Global South often face limited access to funding, expertise, and research infrastructure (Rahman, 2018). And as we have just seen in our bibliographical review (Chapter 3) there are few researchers, as well as institutions, support and funding, from the so-called global south. Therefore, from the perspective of global climate justice, it is vital that governments and international organisations invest in and strengthen capacity-building initiatives to ensure the meaningful participation of researchers and local communities on equal footing. Ensuring effective participation will require strategies that foster trust and information-sharing, thereby reshaping the power dynamics of scientific knowledge production. In this process, humility, active listening, and a deep understanding of local values and assumptions (Jasanoff, 2003) are key to achieving transformative and impactful science.

Finally, we think health impacts can play a key role in SRM public engagement to bridge the gap between science and society. And it can be a useful tool to incorporate and pay more attention to.

Chapter 7. Governing SRM for a healthy climate future[129]

Introduction

In chapter 5 we presented ethical and governance frameworks that can be mainly used at the domestic level. We pointed out the little development of the proposal regarding international coordination and cooperation. This chapter moves to the international arena and to WHO's possible answers to SRM governance. It proposes some ethical considerations for an anticipatory governance framework to align current considerations on SRM with the health protection mandate and policy frameworks of the World Health Organization (WHO) and its Member States. It provides policy options, guardrails, and measurable indicators to equip the health community to lead these deliberations from a "health-first" and "do-no-harm" perspective in the form of considerations , access points for WHO action, and the rationale for principles and guidelines. While SRM introduces new uncertainty layers, worsening climate-health baselines among other issues, require rethinking the precautionary ('do no harm') principle, i.e., not all inaction is safe, and precaution does not have to mean paralysis; it can mean procedural readiness.

1. Brief framing of SRM governance as in its exploratory phase

SRM governance is currently in an exploratory phase, particularly concerning health implications and the mandate of the WHO and its member states. Despite this nascent stage, specific markers for SRM and health must be identified to aid in decision making around its research, potential technology development, and eventual use or non-use. SRM is rapidly entering scientific investigations and deliberations at various levels (from institutional to global) because of the global failure to tackle the worsening climate crisis.

As we have seen in our elaboration of the literature (see Chapter 3), in principle, the scientific, engineering and technical deployment aspects of SRM are fairly feasible in the medium term (Lee et al., 2021). However, the governance and decision making processes around SRM present immense challenges due to the scalable, high impact, global nature of these proposed technological interventions. These aspects are further complicated by the fact that these interventions are much cheaper to develop and deploy (Lee et al., 2021; Smith, 2020; Robock, 2008) as compared to combatting climate change, implying that global powers, with the technical capacities and resources to pursue such strategies, could do so unilaterally or as coalitions of countries. Beyond the moral hazard, slippery slope and climate adaptation and financial deterrence concerns raised around the governance of SRM, uninformed, rash and/or non-cooperative pursuit of SRM research, technologies development or potential deployment can exacerbate the very climate and health inequities that these technologies would aim to reduce.

From a governance standpoint, as we have seen before (see Chapter 1), the decisions around SRM must differentiate between research and deployment, which has implications for the climate-

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health work of the WHO.

Research governance can enable or restrict scientific endeavors around SRM. In general, principles of academic freedom favor curiosity-driven scientific pursuit according to the interests and needs identified by the scientific community. Since SRM research is about exploring these technologies' potential as a "solution" to the climate crisis, and the development and deployment of such technologies would generate a global impact on nations and communities, its research governance inherently becomes a need that may supersede academic freedom. SRM research governance, therefore, must contend with whether and how to conduct SRM research, operating with the utmost care for public perceptions and consent, defining the scope of research, and integrating physical and social sciences to build evidence that can aid in legitimate decision making. In short, it is about how scientific inquiry of SRM is authorized, monitored, and shared.

Deployment governance concerns how actions with population-level exposure are constrained, overseen, or prohibited. This form of governance is overtly anticipatory, and must grapple with the profound, large-scale, and potentially irreversible consequences of SRM implementation. It moves beyond the oversight of scientific inquiry to address fundamental questions of international legitimacy, authority, consent, and accountability, and establishes who would have the authority to make deployment decisions, under what conditions, and on behalf of whom. It must also define mechanisms for global monitoring, control over the "thermostat", and liability and redress for transboundary or unforeseen harms (also true for outdoor experiments in SRM research governance).

2. Case studies highlight governance gaps

Activities around SRM have increased drastically from various domains in recent years, highlighting critical governance gaps. These gaps can be seen in a range of activities at the private, regional and global levels:

- Unconsult SRM research and non-research activities (e.g., in Mexico by Make Sunsets)[130],
- Halted research experiments (e.g., in Alameda, California by the University of Washington, and the SCoPEx project from Harvard University)[131],
- Private sector investments (e.g., Stardust Solutions)[132],
- Public funding (e.g., UK Advanced Research and Invention Agency's approximately £57 million Exploring Climate Cooling Programme, which includes small-scale outdoor experiments[133], multi-million dollar EU funded projects, a now-defunct Chinese SRM research program, and small funding for an Indian SRM research effort),

[130]Make Sunsets (2025). For a critical analysis see Carabajal et al. (2025).
[131] Keutsch Group. ScoPEx (2025).
[132] Stardust Solutions (2025).
[133] ARIA (2025).

- Government reports (e.g. NASEM, 2021), a Congressionally mandated US White House research plan and governance framework (OSTP, 2023), and an EU scoping, evidence, and scientific opinion) (Directorate-General for Research and Innovation, 2024),
- Regional declarations and resolutions (e.g., African Ministerial Conference on the Environment[134]), and
- Philanthropic and non-governmental activities (e.g., Environmental Defense Fund[135]), ETC Group[136], Heinrich Böll Stiftung[137], HOME Alliance[138], Quadrature Climate Foundation[139], Reflective[140], SRM360[141], The Alliance for Just Deliberation on Solar Geoengineering[142], The Degrees Initiative[143], and many others).

Many of the activities being undertaken by the variety of social and institutional actors outlined above, both for and against SRM research, engagement and deliberations on technology development or deployment, are proceeding without international oversight, consultation, public engagement, and global consensus. Some are working to build capacity among academia, civil society and governments to develop consensus on research and/or use or non-use, while others are operating in a non-transparent manner, with no clarity on motivations and end goals. The plethora of activities and actors, and the growing interest and momentum around SRM, demonstrates the clear and present risk of unilateral, bloc-based or non-inclusive action that will have repercussions for public health and more. This was also outlined by EGE (2024) that worried about the unilateral and dual use of these technologies. This underscores the urgent need for the operational frameworks recommended here.

3. Relevant WHO ethics & guidance and policy pathways

The governance of emerging technologies requires a robust ethical foundation to navigate the complexities of global risk and social impact. The World Health Organization (WHO) has developed several key frameworks that offer critical pathways for managing high-stakes research and innovation.

- **Global guidance framework for the responsible use of the life sciences:** Provides a model for managing "dual use" (research where activities intended for benefit might be

[134] United Nations Environment Programme (2025).
[135] Environmental Defense Fund (2025).
[136]ETC Group (2025).
[137] Heinrich Böll Foundation (2025).
[138] Hands Off Mother Earth! (2025).
[139] QC Foundation (2025).
[140] Reflective Institute (2025).
[141]SRM360 (2025).
[142] SG Deliberation (2025).
[143] Degrees NGO (2025).

misapplied). This is one of the dangers of this technology if it is used unilaterally by particular countries (WHO, 2022b).

- **Ethics and governance of AI for health:** Offers a strong precedent for mandating transparency, "explainability," and independent audits for complex, high-risk technologies (WHO, 2021a).
- **Guidance on social listening in infodemic management:** Provides a framework for managing the "infodemic" of misinformation and disinformation, which is a significant risk for a polarized topic like SRM (WHO, 2025b).
- **Ethics of health research priority setting guidance:** Emphasizes that decisions about what research to conduct and how should be made explicitly, systematically, and guided by ethical principles that include social value optimization, use of fair procedures, funding declarations, and inclusion mechanisms that counter marginalization and power imbalances (WHO, 2025a).

4. Policy pathways for the WHO and its Member States

Given this complex landscape, the WHO and its Member States face a spectrum of policy options, each with legitimate justifications and concerns. These policy pathways are reflections of some key governance and ethical frameworks, and highlight that precaution can mean procedural readiness and anticipatory thinking, it does not have to mean paralysis. As -we have just seen in section 2- there are nowadays many activities undertaken without any international oversight.

The policy pathways below are presented as possible options. There is no single "right answer." Appropriate choices will vary with the trajectory and distribution of climate-health impacts, how power and authority are exercised considering perceived risk–benefit trade-offs, and the technical and financial capacity of institutions to meet their mandates (see Postface). What ultimately confers legitimacy is early, ethically grounded, health-first governance that is transparent, participatory, and accountable. These principles apply distinctly to research governance (how inquiry is authorized, research monitored, and shared) and to deployment governance (how actions with population-level exposure are constrained, overseen, or prohibited).

Table 11. Spectrum of possible SRM policy pathways for the WHO to consider

Pathway	Description	WHO Relevant focus
Non-use and monitoring	Reject deployment, observe, report, build surveillance for potential SRM	This pathway leverages the legally binding framework of the International Health Regulations (IHR). Monitoring SRM risks requires the integration of potential atmospheric hazards into national actions plans to strengthen preparedness capacities to address their

	activities.	associated known and unknown risks. The IHR Monitoring and Evaluation Framework has tools like the mandatory State Parties' self-assessment annual reports, which could transparently track national capacities to detect and respond to SRM-related chemical/atmospheric risks. It requires utilizing multisectoral coordination mechanisms already established by WHO and partner agencies (such as WMO and UNEP) aid in the planning process and secure resource allocation, particularly for lower capacity nations and vulnerable communities.
Moratorium with narrow research exceptions	Ban deployment, allow small-scale indoor/lab research.	This pathway requires strict oversight frameworks, drawing on ethical guidance developed for high-risk research. Research must adhere to various WHO guidance provided on life sciences and biorisk governance, which views the oversight of dual-use research as central to ensuring health security. Low-risk activities, such as modelling and observational studies, should continue, provided they are transparent, representative of broad stakeholder concerns, and responsibly governed. Strict transparency is required, aligning with principles of good governance, which should mandate the establishment of public registries of SRM research, documenting funding, protocols, and data disclosure. The principle established under the MEURI framework[144] requires a distinct registry of monitored emergency use protocols (non-research activity) to prevent the mischaracterization of research and non-research aims and ensure appropriate ethical oversight of both.
Conditional time-bound research	Permit limited field trials with expiry and review clauses.	Permitting field trials significantly escalates governance complexities, demanding rigorous, policy-focused assessment and accountability mechanisms. Research must be supported by policy-focused assessments that answer specific questions for decision-makers. This requires the quantification and economic valuation of health outcomes to ensure investments in climate and SRM actions are economically viable from a broader societal perspective, and health conscious. Governance must explicitly address who is liable if harm occurs. Mechanisms must be explored to handle

[144] WHO (2022d).

		potential non-compliance and manage liability risks, considering that responsible entities could include research institutions being liable to communities. Further, permitting field trials requires active engagement with civil society and affected communities. Health and economic valuation assessments must be secured with processes that mandate iterative and sustained stakeholder dialogue with broad groups and their community leaders. Ethical research priority-setting demands an inclusive and transparent process to maximize social value and ensure equity.
Pilot/readiness track	Prepare institutions for possible future emergency use.	This track involves preparing global institutions for potential emergency deployment, which requires robust decision-making and preparedness frameworks that are proactive, not only reactive. Effective SRM governance, in this track, must be cooperative, multilateral, and designed to ensure accountability and broad legitimacy. In such governance, mechanisms to handle non-compliance with formal regulations is highly necessary. Legal "red lines" derived from the CBD resolution and other international conventions should serve as policy triggers.
		The governance must define clear triggers, thresholds, and off-ramps ("red lines") that are categorized by scientific, socioeconomic response, and policy factors, ensuring that deployment choices are carefully structured. Further, defining emergency readiness clearly will require leveraging the various and all-hazards planning tools of the WHO to ensure readiness capacity is maintained. This preparedness must extend to multisource collaborative surveillance (WMO, UNEP, health sector) to manage uncertainties during crises, including emergency use considerations.

4. Policy options and considerations

Consideration 1: Prioritize mitigation and adaptation as climate response options, and mandate non-substitution as an enforceable guardrail

This consideration goes beyond WHO scope but it expresses a shared concern among various stakeholders, institutions and even advocates of SRM. As we have seen in previous chapters (see Chapter 1 and 5, and also in the FCEA Report), to prioritize mitigation and adaptation may function as a precondition for SRM use within an action portfolio of responses to climate change. By non-substitution we understand that if SRM is included in the portfolio, it must not, under any circumstances, substitute rapid and deep reductions of greenhouse gas emissions, adaptation, or carbon dioxide removal (CDR). This principle must be an enforceable, non-negotiable guardrail in view of SRM inherent risks (see Chapter 1, section 1.5).

Possible action points

- **Establish** legal and financial firewalls that explicitly decouple SRM research funding and policy from mitigation and adaptation commitments.
- **Prohibit** the use of SRM as a "credit" or "offset" for compliance with Paris Agreement targets (Nationally Determined Contributions).
- **Require** demonstrated progress on mitigation and adaptation as a potential precondition for any staged progression of SRM research.
- **Track** and publicly report on the opportunity costs of SRM research, including the health co-benefits foregone if funds are diverted from proven interventions like clean energy or health system strengthening.

Rationale for non-substitution

As we already pointed out in Chapter 1, section 1.5.2., from the perspective of the entire climate response portfolio, the primary risk of engaging with SRM is mitigation deterrence ("moral hazard", "risk compensation"). This is the concern that the mere discussion of a "techno-fix" could deter or delay the urgent work of decarbonization. SRM does not address the root physical cause of climate change (GHG emissions) and deployment could create a "slippery slope" or "lock-in" with unknown technologies. Advocates for the rejection of SRM cite this as a primary reason to limit engagement. Therefore, any "health-first" governance framework must actively and legally prevent this substitution.

Consideration 2: Anchor all SRM governance of WHO within a "health-first" mandate

All decisions regarding SRM, from research to potential deployment, must be evaluated by taking into consideration its health dimensions. This means prioritizing health and equity over purely technical or risk-based assessments. A health first approach should require proportional and contextual measures at the different SRM stages and the particular life cycle of each SRM climate intervention.

Potential action points

- **Adopt** a human-rights-based approach that explicitly centers health equity, distributive justice, and intergenerational justice in all governance.

- **Leverage** existing WHO resolutions, particularly WHA 77.14 ("global plan of action on climate change and health"), to provide a clear mandate for the health community's role in SRM deliberations.
- **Mandate** proportional, distribution-sensitive Health and Equity Impact Assessments as a prerequisite for any SRM research proposal.
- **Integrate** SRM-attributable signals into existing WHO-guided hazard indices, early warning systems, and national surveillance capacities (e.g., IHR).

Rationale for a health-first approach

Persistent institutional and transparency gaps create health risks. A "health-first" lens is essential because it reframes the SRM debate around a fundamental question: will this intervention reduce human suffering and advance health equity, or will it exacerbate harm?

However, as there is little known about the impact on health (see Chapter 3), we also propose a third consideration.

Consideration 3: Encourage research and knowledge on health impacts within an SRM balance assessment.

This consideration should be applied to modeling scientific literature and include physical and mental health as well as social wellbeing. This is an additional consideration for the WHO when considering a balanced assessment of SRM physical and broader socio-political risks against the risks of climate change that it might prevent (Royal Society, 2025, p. 99).

The WHO is uniquely positioned to lead this framing as well as to operationalize considerations 2 and 3. Its established mandate on climate and health, its trusted role as a norm-setter, and its existing technical frameworks provide the foundation for robust, health-centered research and governance before any decisions are made. This approach moves beyond abstract debates and grounds the discussion in the tangible health outcomes for populations with different vulnerabilities. We will outline some possible norms, resolutions and partners that may be useful.

Key WHO & multilateral levers

WHA Resolutions (e.g., 61.19, 77.14): Provide the mandate to place public health at the center of the climate response and integrate climate across all WHO technical work[145].

International Health Regulations (IHR): This core, legally binding framework for managing public health events of international concern can be leveraged for monitoring and

[145] See World Health Organization (2008) and World Health Organization (2024).

notification of transboundary atmospheric risks and their health implications.

Operational Framework for Climate-Resilient Health Systems: Provides a practical template for preparedness, surveillance, and risk appraisal that can be extended to SRM[146].

Multilateral Partners: Multilateral coordination is essential to integrate SRM into climate-health assessments and the WHO is already undertaking to support decision making on SRM research and potential deployment, as well as to identify and stress test the potentially necessary institutional mechanisms and infrastructure for use/non-use eventualities.

Some relevant multilateral institutional arrangements for the WHO and its Member States to leverage include: the **Intergovernmental Panel on Climate Change (IPCC)**, for producing assessments that outline the pathways for urgent climate action, the impacts on public health, as well as the feasibility and need for SRM; the **World Meteorological Organization (WMO)**, for the development of key indicators to monitor SRM attributable signals relating to climate-health risks and embedding such information into early warning systems; the **UN Environment Programme (UNEP),** for upholding environmental norms, particularly by extending assessments on the interplay of GHG emissions, air quality, and health burdens (incidence of death, disability and disease) to include various proposed SRM aerosols; the **Convention on Biological Diversity (CBD)**, for ensuring the WHO stays aligned with its precautionary decisions on geoengineering broadly (inclusive of SRM) (see Chapter 2, section 1) and provides input on how biodiversity and health parameters may change under climate change and specific SRM interventions/scenarios; and the **Green Climate Fund/Global Environment Facility**, by supporting Member States with guidance that integrates SRM aspects into their climate and health readiness processes, such as by developing their capacity to pitch for and receive finance that integrates health co-benefits into their climate mitigation and adaptation projects, and determining whether and how SRM alters health co-benefits.

Finally, it is crucial to mention the **UN Framework Convention on Climate Change (UNFCCC)** and **the Paris Agreement**, which provide the ambition for climate action (maintaining global average temperatures to 1.5°C, or well below 2°C, as compared to pre-industrial levels) and mechanisms to achieve those thresholds (Nationally Determined Contributions (NDCs) that ramp up mitigation, adaptation, and financing). With the UNFCCC and its Conference of Parties continuing to remain silent on SRM, likely as a political signal to not distract from the urgent climate action outlined in the Paris Agreement, it has created a vacuum that other multilateral institutions are attempting to fill, resulting in a fragmented approach overall.

Consideration 4: Design an international, anticipatory system of governance

To manage the profound uncertainties that exist in defining the risks and benefits of SRM as found in growing research literature, principles of good governance must be translated into

[146] See World Health Organization (2023).

operational rules. A robust framework requires public mechanisms that promote climate and health-first justice orientation. Such a framework must reflect meaningful inclusion of the interest of populations that will be most impacted and that historically lacked resources and voice. It must also include transparency, independent oversight, and course correction that can ensure SRM and its health dimensions are deliberated based on well-governed and equitably representative scientific evidence, inclusive decision making processes, and strong accountability mechanisms.

Potential Action Points

- **Establish** a global public registry for all SRM research and non-research activities in an accessible manner, especially health impacts and public health implications, mandating pre-registration of protocols, funding sources, conflict-of-interest statements to prevent the mischaracterization of research and non-research aims and ensure appropriate ethical oversight of both.
- **Ensure** the interests and voices of disempowered populations of the different regions and countries are taken into account.
- **Define** and pre-register clear scientific, public response, and policy-based "thresholds", "triggers" and "off-ramps" (Table 11) before any outdoor research begins.
- **Create** independent oversight bodies with the authority to approve, pause, or terminate SRM research and non-research activities based on predefined thresholds, especially if health outcomes are undermined (Table 10).
- **Ensure** procedural integrity through early, continuous, and intelligible public engagement, including the use of social listening to manage infodemics and disinformation.
- **Implement** accessible, safe, and time-bound grievance and redress mechanisms, including pre-committed funds to address potential health harms.

Rationale for an operational framework

Good governance is not optional; its absence creates health risks. An operational framework moves beyond principles by creating enforceable rules. It also helps outline the types of necessary research that can aid in decision making based on health dimensions. Further, defining "red lines" (triggers and thresholds) *before* SRM research moves to outdoor experiments is the only way to manage the risks and uncertainties that may occur as unintended outcomes. This may secure public trust in the research processes and findings, it should also broaden the scope of research by including specifications of all stakeholders impacted, and build legitimacy around deliberations and decision making. If a scientific signal, a policy breach, or a collapse in public legitimacy occurs, the system must have a pre-agreed "off-ramp" to pause, review, and remediate. In Table 11 we outline some possible examples of thresholds, triggers, and off-ramps if it were to be accepted for outdoor experimentation and potential phased deployment; as this is one of the most controversial aspects of SRM.

Table 12. Simplified example thresholds, triggers, and off-ramps for outdoor experimentation and potential phased deployment

Category	Threshold (Breach)	Trigger (Signal)	Off-ramp (Action)
Scientific	Pre-agreed variance band from baseline for relevant climate and health indicators.	Anomaly detected in aerosol/ozone/UV monitoring networks.	**PAUSE** activity. Notify authorities. Conduct attribution analysis. Do not resume without redesign.
Public Response	Composite legitimacy and public trust indices drop below pre-set floor in a specified time period.	Sustained negative trend in public trust/legitimacy metrics.	**PAUSE** non-urgent activity. Undertake enhanced public engagement. Commission independent facilitation. Re-assess, and if necessary terminate activities.
Policy	Operationalized oversight body.	Validated findings that outdoor research proceeds without prior notification or public registration.	**TERMINATE** authorization. Publish rationale. Initiate liability/remedy process.

A critical challenge that any operational framework around SRM must address is when enough information is present to warrant a complete rejection of further SRM research or deployment. While this would have to be accounted for in operational frameworks of a variety of institutions, particularly international agencies like the UN Environmental Assembly and Programme, for the WHO and its Member States, bringing in the health dimensions as crystallized go/no-go inflection points would help shape the future of SRM research governance, and inform potential deployment pathways.

Consideration 5: center equity, justice, and co-stewardship by the Global South and communities with vulnerabilities

A health-first governance approach must be cognizant of roles, responsibilities and perspectives of the Global South and vulnerable communities. As such, equity and justice must serve as necessary preconditions for legitimacy and scientific quality. While the WHO and its Member States adhere to these principles through various guidance (some presented above), specifically charting them for health considerations will center equity, justice and co-stewardship of Global South and representatives of vulnerable communities to build/implement appropriate SRM governance mechanisms.

An additional consideration —in light of what was already underscored in previous chapters—and that complements this fifth consideration is as follows:

Consideration 6: Consider the interests, voices, and specificities of the different countries and

regions of the Global South.

The Global South includes very different regions each of them with different challenges and particularities in relation to climate change, SRM, illnesses and health systems. One is the situation of Latin America with countries in the equator while others are near Antarctica; quite different is the situation of Pakistan or Vietnam as well as many countries in Africa (one is the situation of Malawi while other is the one of South Africa or Morocco). As already argued, it is unlikely to be useful to use the Global South as a blanket term, but instead, to use it as a starting point to investigate vulnerabilities affecting the majority of people's health.

Rationale for justice-oriented (equitable) and Global South-forward governance

Climate and health risks are unequally distributed; those least responsible are most vulnerable. SRM governance must not reproduce these historical and ongoing climate related inequities, least of all for health concerns. SRM research and governance models require shifting power and resources away from Global North-centric philosophies of climate intervention (whether outright rejection or accelerated deployment trajectories) and towards the growing, dire climate impacts felt by climate vulnerable communities and Global South constituents.

Making equity measurable and enforceable ensures that *who* participates, *how* resources flow, and *who* bears risk are tracked with the same discipline as scientific data. If equity metrics (e.g., funding for capacity sharing, region-specific and endogenous/local knowledge generation) are missed, they must trigger a pause of SRM research or decision making activities, and create clear pathways to address the shortfalls, thereby treating a failure of justice as a failure of the entire process.

Co-opting WHO's tools for health equity

- **WHO Global Strategy on Health, Environment and Climate Change:** Prioritizes primary prevention, strong governance, and cross-sectoral action, directly applicable to SRM's intersectoral nature (WHO, 2020).
- **COP26 Special Report (The Health Argument for Climate Action):** Provides the core argument for centering health and social justice in all climate decisions (WHO, 2021c).
- **A Framework for the Quantification and Economic Valuation of Health Outcomes Originating from Health and Non-health Climate Change Mitigation and Adaptation Action** (WHO, 2023) **+ Climate Change and Health Vulnerability and Adaptation Assessment** (WHO, 2021b)**:** The economic valuations provide WHO Member States with systematic guidance on climate-health policy analysis for determinations of sectoral and cross-sectoral climate mitigation and adaptation inaction versus action, while the assessments emphasize the climate-health vulnerability and adaptation needs of Member States to proactively manage climate-health risks and increase system resilience.

- **National Action Plan for Health Security Strategy 2022–2026** (WHO, 2022c)**:** Translate the above assessments into actionable, priced plans (specifically, National Health Adaptation Action Plans), using a multisectoral, all-hazards, whole-of-government approach. Per the requirements of the IHR and its Monitoring and Evaluation Framework, accountability is held at the highest possible national level to ensure involvement from sectors like environment and finance, crucial for SRM oversight.

We recommend possible options for next steps:

- **Encourage** Global South co-leadership and shared decision-making rights on all governance bodies, protocol design teams, and review committees.
- **Ensure** Global South's interest are acknowledged in all its diversities and particularities (ie. small island in the Caribbean prevailing illness and health systems capacities might be different from Sub-Saharan Africa or developing Asia).
- **Ensure** the use of contextualized and situated approaches to support inclusive deliberation on SRM, acknowledging that no single model or 'one-size-fits-all' approach can adequately address all contexts.
- **Explore** dedicated funding, timelines, and budgets for genuine capacity sharing (beyond capacity building), including equipment, training, data systems, and mirrored monitoring infrastructure to be hosted in Global South institutions.
- **Implement** and publicly report on a governance framework that incorporates equity metrics, which track funding flows, participation parity, language access, and local data and technology development stewardship, among others.
- **Ensure** participation standards remove barriers by providing honoraria, translation, accessibility accommodations, and support for communities and Global South representatives to engage with, deliberate, and effectively shape SRM decision making.

5. Final considerations

This chapter provides ethical considerations as well as policy options; guardrails and measurable indicators that WHO can consider in order to build an anticipatory governance framework. It also explores some of WHO ethical and guidance documents that may help in this endeavor. In total, we propose six governance considerations, as per the Executive Summary and Concluding remarks:

1) to prioritize mitigation and adaptation as climate response options, and mandate non-substitution as an enforceable guardrail;

2) to anchor all SRM governance of WHO in a "health-first" mandate;

3) to encourage research and knowledge on health impacts within SRM balance assessments;

4) to design an international anticipatory system of good governance

5) to center equity, justice and co-stewardship by the Global South and communities with vulnerabilities,

6) to consider the interests, voices and specificities of the different countries and regions of the Global South.

Part IV. Final remarks

Concluding remarks and considerations

1 - This Report found a scarcity of studies on health impacts of SRM. We call for more empirical research on this understudied topic. The available studies converge on the understanding that health impacts are likely to be unevenly distributed at a regional climate scale and are likely to interact with existing climate-health gradients.

2 - The Global South and health perspectives on SRM ethics and governance are currently lacking from global science-policy debates. Yet the way in which we integrate these perspectives matter. Through a careful analysis of terms like "geoengineering", "SRM" and "Global South," we have attempted to emphasize that ethics and governance for SRM should not rely on a one-size-fits-all approach. This is why we stress that public participation in SRM research and debates about potential deployment is required. This is because that research should identify climate-health needs and work with local populations to elaborate fair policies to meet them.

3 - The authors of this Report consider that the WHO can play an important role in assessing and guiding SRM research and questions about its use or non-use options through a health-first governance lens, as per the perspective in Chapter 7. This lens could be useful to ground governance so that decisions on SRM that are safer, fairer, and more intelligible to health systems.

4 - The postface and annexes go into greater detail on some of the finer details related to the policy dimensions of SRM (including the need for procedural fairness and potential compensation schemes), technical details, and more extensive terminological analysis.

Ethical considerations:

1) to prioritize mitigation and adaptation as climate response options, and mandate non-substitution as an enforceable guardrail;

2) to anchor all SRM governance of WHO in a "health-first" mandate;

3) to encourage research and knowledge on health impacts within SRM balance assessments;

4) to design an international anticipatory system of good governance and

5) to center equity, justice and co-stewardship by the Global South and communities with vulnerabilities, and

6) to consider the interests, voices and specificities of the different countries and regions of the Global South.

Postface. Fairness and public acceptance of SRM policy[147]

Introduction

People are more likely to support a policy when they think it has fair outcomes (André et al., 2022; Haidt, 2013). People perceive policy outcomes as fair only when, at the very least, the policy produces no net losers (André et al., 2022).

All SRM policy pathways can have mixed health outcomes. They can simultaneously increase health risks for some people, and decrease health risks for other people. For this reason, all possible SRM policy pathways—from a strict indefinite moratorium on research and deployment, to full deployment—are likely to produce at least some net losers. In a complex, dilemmatic case like this, the public is more likely to accept SRM policy pathways if they are procedurally fair, and if net health losers are fully compensated.

1. People care about fairness

People are more likely to support policies when they perceive them as fair. This means both that the outcomes are fair ('outcome fairness') and that policy decision-making procedures are fair ('procedural fairness').

Before explaining these concepts it is important to mention that even though people care about fairness, it is not all they care about. The fact that a policy choice is fair is neither necessary nor sufficient for people to support it. People may reject a policy they agree is fair, and they may endorse a policy they agree is unfair. The reason is that moral motivation has limits. People often succumb to the temptation to act immorally when they believe that cheating may go unnoticed, the benefits from cheating are very high, or levels of trust are low (Lie-Panis & André, 2022).

1.1. Outcome fairness

People accept or reject policy partly on the basis of its expected outcomes (Ajzen et al., 2018; Eagly & Chaiken, 1993). One key way in which people assess expected policy outcomes is in terms of their fairness (André et al., 2022; Haidt, 2013).

There is disagreement on how to define and measure outcome fairness. There is however broad agreement and strong evidence that people regard as unfair any cooperation whose outcome is not mutually beneficial (André et al., 2022; Curry, 2016; Gray et al., 2012; Haidt, 2013). Cooperation is *mutually beneficial* when no participant is left worse off than if they had not cooperated—i.e. when cooperation produces no net losers[148]. This matters for policy choices. Policy choices set out the terms by which people cooperate. People are likely to think that a policy that produces net costs for some people is unfair.

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[147] Main contributor: Francisco Garcia-Gibson.

[148] Mutual benefit is not enough for fair outcomes, but it is the absolute minimum (André et al., 2022).

Mutual benefit should not be confused with aggregate benefit. The *aggregate benefit* of cooperation is the sum of all benefits minus all costs across all cooperators. A policy may produce large aggregate benefits without being mutually beneficial for all. This is true for example when the costs a policy imposes on some people are less significant than the gains it provides to others—so in the aggregate the policy is beneficial—yet the people who pay costs get no benefits from the policy—so the benefit is not really mutual but instead unilateral. There is compelling evidence that people only see as fair outcomes that are mutually beneficial (Moore et al., 2024; White et al., 2024). For this reason, people are unlikely to think that SRM policy is fair if its benefits are not mutual—even when the losses the policy imposes on a person are much less significant than the gains it provides to others.

1.2 Procedural fairness

Fair outcomes are not all that people morally care about. People also care about fair procedures. People care if decisions about how to cooperate were made through a fair decision-making process (Besley, 2010; Gross, 2007; Tyler, 2000). Procedural fairness has a powerful independent effect on public support, especially when a policy's outcomes are hard to ascertain or unknown (Tyler, 1996, 2000).

Calls for procedural fairness in SRM policy are common (NASEM, 2021), particularly calls for procedural fairness regarding the Global South (Jinnah & Dove, 2025). As chapter 6 explains, procedural fairness in SRM policy requires inclusive and meaningful public engagement. This entails establishing transparency, independent oversight, and participatory mechanisms. Vulnerable communities should actively contribute to shaping decision-making processes and research priorities, rather than merely reacting to technocratic decisions.

2. Most SRM policy pathways inevitably create net losers

There is a wide range of SRM policy pathways (see Chapter 7). These policy pathways set research and deployment rules, with alternative pathways ranging from an indefinite ban on both research and deployment, to an eventual regulated permission for both. Given its potentially planetary effects, all SRM policy pathways are likely to influence health risks for practically every human for many generations. For some, SRM policy may increase health risk; for others, SRM may decrease health risk. For this reason, any SRM policy pathway is likely to produce at least some net losers. In other words, every SRM policy pathway is likely to increase the net health risk for at least some people.

To illustrate how all SRM policy pathways are likely to produce net losers, let us consider a small set of SAI policy pathways and some of their potential health effects. As explained in chapter 3, there is substantial uncertainty about the health effects of alternative SAI policies. Nevertheless, we can consider some hypothetical effects. One possible SAI policy pathway is to first allow for time-limited SAI field trials, prepare institutions for possible deployment, and finally allow for deployment within guardrails. This policy pathway may reduce health risk for many people. This is because eventual SAI deployment could help lower the temperature peak in this century. A higher temperature peak means worse heatwaves, for example, and increased heat-related mortality. Now, SAI deployment may well pose some health risks of its own (see chapter 3). For some people in some parts of the world, these potential health risks may not outweigh any potential health (or other) gains for them from SAI deployment. These people would be net losers from SAI policy.

Any alternative SAI policy pathway is likely to create net losers too. Consider another pathway: an indefinite moratorium on all SAI research and deployment. This policy pathway may reduce mitigation deterrence risk, increasing the likelihood that long-term decarbonization goals are reached and long-term health climate impacts minimized. Yet banning all SAI research and deployment may simultaneously increase the risk of temperature overshoot. Temperature overshoot involves many risks, including heat-related mortality risks for many people. People who face this increased health risk would be net losers, because any health benefit these victims may derive from the full moratorium is probably outweighed by the huge cost of a higher death risk from a heat shock.

Similar dilemmas occur for most SRM technologies. Since any SRM policy is likely to produce net losers, any SRM policy is likely to be regarded as unfair (unfair outcomes).

3. Fair procedures and compensation for net losers

SRM policy is not the only policy domain where all options create some net losers. All complex, large-scale policy choices are very frequently dilemmatic in that very same way. Federal economic policy, for example, almost always creates at least some net losers. Trade-offs are unavoidable.

In these dilemmatic cases, unfairness perceptions can be dramatically reduced or even eliminated by compensating net losers. In other policy areas there is evidence that compensation for net losers can foster public acceptance of policy (Saglie et al., 2020). A compensation scheme for SRM harms surely presents ethical and implementation challenges (Svoboda & Irvine, 2014), but these challenges are likely surmountable (Wong et al., 2014).

If an SRM policy pathway is adopted that allows for eventual SRM deployment, an international fund could provide financial compensation for harms to health. Compensation can be provided without the need to establish liability—which may deter deployment—or a causal link—which may be technically infeasible—(Reynolds & Horton, 2020). If, on the other hand, the adopted policy is a ban on SRM deployment, compensation could take standard forms of climate adaptation and loss and damage transfers. Importantly, compensation mechanisms must themselves be procedurally fair for compensation to be effective in promoting support for policy (Jørgensen et al., 2020).

4. Final considerations

All SRM policy pathways produce net health losers, so many people are likely to regard SRM policy as unfair. A key way to mitigate these unfairness perceptions is to ensure that all SRM policy decisions are procedurally fair, and set up mechanisms to compensate net health losers.

Part V. Annexes and references

Annexes

Annex 1 - Chapter 1[149]

Here, we aim to make a first conceptual approximation to the research ethics and governance of solar radiation modification (SRM) or solar geoengineering (SG) through an analysis of the terminology, starting by the neutral aim-based definition of the umbrella term geoengineering that includes ethics and governance on SRM research. More recently, the most authoritative ethics and governance reports have abandoned the term geoengineering to focus more specifically on SRM exclusively (e.g. Royal Society, 2025). Also, as we show below, because of the possibility of repurposing SRM to alleviate climate impacts for other commercial purposes (e.g. weather modification, terraforming of other planets or satellites) and the potential role of intervention repurposing as an enabler or barrier for responsible SRM research, there is a need to widen the lenses of SRM research ethics. Hence, for historical and practical reasons, we start with the conceptual analysis of the term geoengineering, and then move into SRM.

It has previously been recognised in the scholarly literature on climate change that the unclarity of concepts is deeply problematic. Choosing good definitions is important to be able to make true statements about reality (Werndl, 2016) as well as for effective action (Mastroleo & Holzer, 2020). In this way, definitions have knowledge-related and practical-related functions. Moreover, because of definitions' practical consequences, they are unlikely to be neutral from a social and/or ethical point of view, and it is important to make value judgments found within definitions explicit (Lam, 2022). Thus, the way we define geoengineering has important implications for how we perform an ethical analysis of it (Frosch, 2009), making definitions a solid starting point for this report on ethics and governance.

The practical main aims of SRM research (e.g., contribute to resolving uncertainties or generalizable knowledge) and deployment (e.g., alleviate climate change impacts (see Box 1) are not outcome-neutral, because they partly define the boundaries of what is ethically permissible or not. However, the terms we use to identify SRM interventions should be neutral to logically allow for the distinction between irresponsible and responsible cases. If not, definitions would be doing the work of ethical principles. But we have identified negative, neutral, and positive connotations of the term geoengineering as well as of SRM (see Chapter 2). And only neutral connotations of the terms geoengineering and SRM allow for an unbiased ethical evaluation.

[149] Main contributors: Ignacio Mastroleo and Timothy Daly, based on Mastroleo (2025a, 2025b)

Box 1. Reconstruction of the main practical aim of SRM deployment: "alleviating impacts of climate change" (IPCC, 2012) including adverse consequences to health and ecosystems

1. SRM is an action. Like the term "geoengineering", "solar radiation modification" (SRM) refers to an action or activity (means-end structure), not merely to the hardware of climate interventions or the physical variables of modification.

2. Alleviate the impacts of climate change (end) is the practical main aim of SRM in IPCC's neutral definition of geoengineering [pre-AR6]:. "[Geoengineering is] a broad set of methods and technologies that aim to deliberately alter the climate system [means of geoengineering] in order <u>*to alleviate the impacts of climate change*</u> [practical main aim or end of geoengineering]. […] [some] methods seek to […] (1) reduce the amount of absorbed solar energy in the climate system (solar radiation management, or solar radiation modification, SRM) […]" (IPCC, 2012, p. 2, quoted in IPCC, 2019, edited, emphasis added).

3. SRM neutral definition of IPCC's Glossary AR6 captures the scope of a subset of technical means to alleviate the impacts of climate change. "[SRM] refers to a range of radiation modification measures not related to greenhouse gas (GHG) mitigation that seek to limit global warming. Most methods involve reducing the amount of incoming solar radiation reaching the surface, but others also act on the longwave radiation budget by reducing optical thickness and cloud lifetime" (IPCC [AR6], 2021, edited).

4. Impacts of climate change include adverse consequences to health and ecosystems according to the IPCC's Glossary AR6 definition "The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, <u>*health and well-being, ecosystems and species*</u>, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial" (IPCC [AR6], 2021, emphasis added).

5. Alleviate means "to make something less severe" according to the Oxford Dictionary.

To note, the neutral definition of geoengineering typically adopts the standard scientific interpretation of the Earth climate system as a complex large-scale physical system, not as a religious view (Morton, 2016, pp. 290-291). From a merely physical perspective, there are no differences between deliberate changes in the Earth climate system made by responsible agents (e.g. cooling the Earth's surface using space mirrors) or unintended side effects of deliberate changes (e.g. cooling the Earth's surface as a side effect of pollution generated by transatlantic ships) and non-deliberate changes by non-responsible agents or physical events (e.g. the cooling effect of the Earth's surface as an effect of a non-intervened large volcano eruption, such as Mount Pinatubo in 1990s). From a physical perspective combined with an intentional point of view, we describe these changes respectively as actions (including their practical main aims and means), side effects of actions and physical events, and they typically receive different ethical evaluations and have different ethical status. Unfortunately, all these different types of changes in the Earth climate system have been referred to as "geoengineering," whether deliberate or not.

For ethics and governance analysis, it is important not to confuse different stances or points of view of an object or a system, particularly the merely physical and the physical-intentional stance, that includes both the design or technical stance and the ethical stance that are aim-based (Dennett, 1989)[150]. We can describe or evaluate the same object or system from a merely physical stance, based on physical laws (e.g. a certain amount of aerosols in the stratosphere is capable of reflecting a certain amount of incoming solar radiation). Or from a design or technical stance, merely based on functionings and conceptual design (e.g. to inject aerosol in the stratosphere, different design of planes are required to reach tropical or polar injection), and from an ethical stance, the point of view that regards activities not as merely physical movements but also as actions by responsible agents (e.g., the main aim of SRM is to alleviate adverse consequences of climate change, but it may imply unintended harmful side effects that require appropriate responses).

This analysis of geoengineering, including SRM, as a deliberate intervention has practical consequences. Ethics and governance of SRM research requires both physical and intentional stances of analysis. This could be expressed by the formula that ethics and governance of SRM research without a physically informed point of view is empty, and without an intentional point of view is blind.

There is also a danger of literally interpreting the Royal Society's and IPCC's definitions of geoengineering, that include SRM as one of its main categories, as only referring to large-scale uses[151]. This clarification is important for ethics and regulation of SRM research and non-research experiments. The term large scale typically refers to the end-stage of the life cycle of potential geoengineering interventions, while the activity of experimentation at different scales within and outside research is often related with a process activity that involves previous non-large or non-planetary versions of such interventions that may lead or not to a larger regional or planetary version. If authorities are responsible of governing the end product and its consequences, from a practical point of view, they should also have responsibility for governing the means or enablers of that end product, in this case research experiments (e.g. SCoPEx, exemplary case of small scale outdoor field trial) and non-research experiments (e.g. Make Sunsets, exemplary case of start-up selling cooling credits based on small-scale SRM deployment) (Carabajal et al., 2025). The concept of experiment in ethics and governance of SRM should be explicitly defined and used with a neutral attitudinal connotation to allow for identification of responsible and irresponsible instances (Carabajal et al., 2025; Mastroleo, 2025b).

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[150] *Morton's definition of geoengineering (wide scope) as climatic and non-climatic deliberate change to the Earth system*. "When the change that humans bring [agent] to this new Anthropocene state of the earthsystem [sic.] [context] is deliberate, I see it as geoengineering; in this book, that term [geoengineering] will cover any deliberate technological intervention in the earth system on a global scale, not just those aimed at countering, or ameliorating, the changes that people are making to the climate without deliberation" (Morton, 2016, p. 26, edited).

[151] This may come for our tendency to interpret geoengineering interventions, including SRM, as finished objects or end products (e.g. the material dimension or hardware of geoengineering interventions) instead of as an action that develops through the time or life cycle in different stages (e.g. "geoengineering the climate" (Shepherd & WGGC, 2009), "intentional climate change" (Jamieson, 1996).

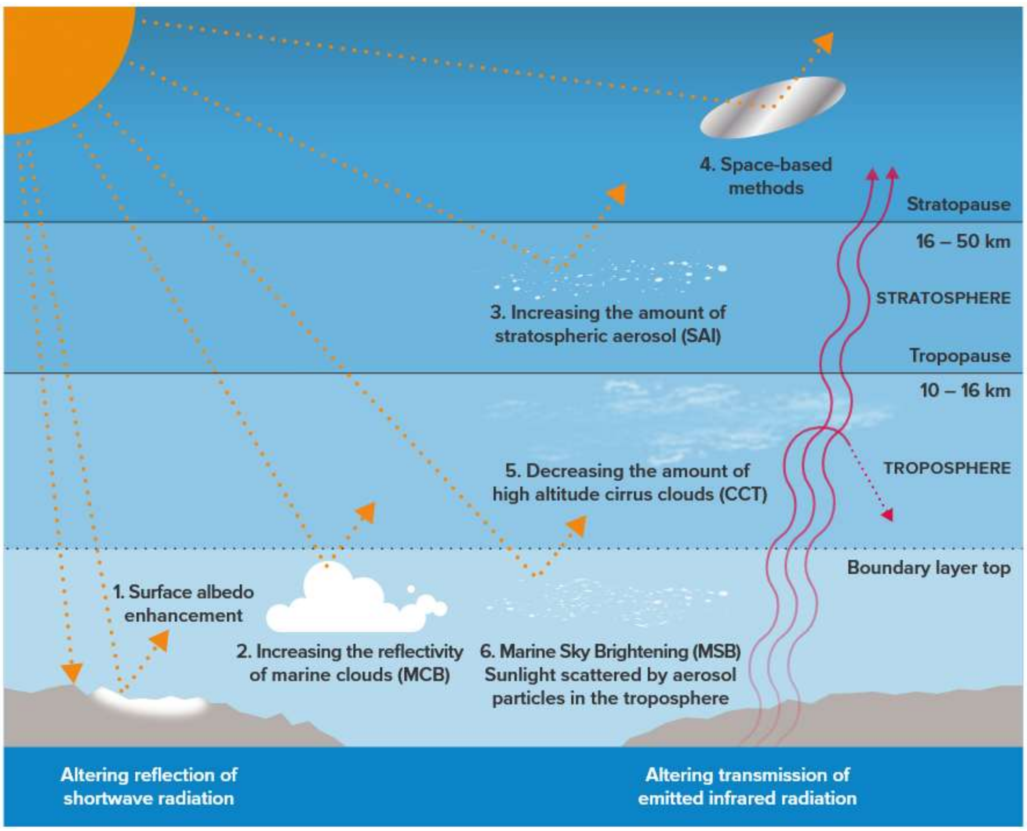
It is important to come back to the importance of the practical main aim or end of SRM. First, as the neutral definition of geoengineering refers to an action or activity (means-end structure) and not a thing, so too does SRM refer to an activity and not just the hardware dimension or the physical variables that climate interventions intend to modify. Within SRM ethics and governance, an important question that structures it is "Why should we do SRM, if at all?" or "What is the main aim of doing SRM, if at all?". Second, defining the practical main aim broadly limits the range of ethically permissible action (e.g. commercialization of SRM) or impermissible actions (e.g. military or hostile use of SRM) and require articulation with other important ends within SRM (e.g. research, deployment, monitoring) and between SRM and other actions (e.g. cutting emissions, CDR, adaptation). For example, the practical main aim of SRM research, a stage or part of the life cycle of the SRM action, is to contribute to generalizable knowledge or resolve uncertainties about different uses or non-uses of SRM interventions. However, the practical main aim of potential deployment of SRM is not contributing to knowledge or resolving uncertainty, it is alleviating impacts of climate change, including health negative consequences or outcomes.

Annex 2 - Chapter 2[152]

2.A. Typical scope of SRM, variables of modification and exemplary cases

See below Figure 2.A.1. the Royal Society (2025) typical scope of that SRM climatic intervention that refers to the modification the amount of energy in the climate system either of incoming solar radiation in yellow (short-wave radiation, augmenting reflectivity, e.g. SAI or blocking solar constant e.g. Space mirrors or other Space-based methods) or outgoing trapped radiation in red (long-wave radiation, enhancing emissivity, e.g. cirrus cloud thinning (CCT)) (e.g. IPCC [AR6], 2021[153]; COMEST, 2023[154]; Royal Society, 2025[155]).

Figure 2.A.1. Schematic diagram showing the interaction of solar radiation (yellow arrows) and emitted infrared radiation (wavy red arrows) with the various proposed SRM techniques



Source: Royal Society (2025, 17, Figure 3), adapted from WMO (2022).

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[152] Main contributors: Ignacio Mastroleo and Timothy Daly.

[153] "[SRM] refers to a range of radiation modification measures not related to greenhouse gas (GHG) mitigation that seek to limit global warming. Most methods involve reducing the amount of incoming solar radiation reaching the surface, but others also act on the longwave radiation budget by reducing optical thickness and cloud lifetime". (IPCC [AR6, Glossary] 2021, edited). See also Box 1.

[154] "Solar Radiation Modification (SRM): through atmospheric interventions that either reflect more sunlight back into space or allow more infrared radiation to escape into space, these techniques could offset the effects of increased greenhouse gas concentrations" (COMEST, 2023, p. 9).

[155] "SRM involves modification of Earth's energy budget. That budget consists of two components: (i) absorbed sunlight, and (ii) infrared radiation emitted by the Earth and atmosphere into space" (Royal Society, 2025, p. 18)".

Note that the Royal Society definition of SRM in its geoengineering report (Shepherd & WGGC, 2009)[156] has a narrower scope than the IPCC (2012)[157], only including climate interventions capable of modifying short wave incoming radiation and not long-wave outgoing radiation. However, the Royal Society (2025) policy brief changed its scope of SRM in line to IPCC (2012) and others mentioned above, to include climate interventions that modify both incoming and outgoing trapped radiation. However, when referring to CCT, an exemplary case of an SRM intervention for outgoing trapped radiation (see Figure 2.A.1, above), it seems the historical 2009 narrower definition of SRM was at play when it is stated that "*Strictly speaking, cirrus cloud thinning is not an SRM technique*, but it is closely related as it seeks to reduce the thickness and/or coverage of high-altitude cirrus clouds, increasing the amount of infrared radiation that can escape into space, which would lead to a surface cooling" (Royal Society, 2025, p. 37, emphasis added).

Symes (2024a) tries to solve the problem of interpreting "solar radiation" as only incoming short-wave radiation basing the scope of climate interventions on three possible variables of modification, namely, reflectivity, solar constant, and emissivity.

For our reconstructed scope of SRM, we have followed the current broader scope already present in IPCC (2012), currently accepted in Royal Society (2025), and included Symes (2024a) variables of modification in a different column (see Chapter 2, table 3).

2.B.1. Narrow, intermediate and wide scope of geoengineering, planetary engineering and weather modification, plus "unintentional" geoengineering

Table 2.B.1. Comparison of terminological analysis of the term geoengineering, distinguishing narrow, intermediate and wide typical scopes, planetary engineering and weather modification, and "unintentional" geoengineering

Term	Typical scope	Distinctive exemplary cases
Planetary engineering	Non-geoengineering higher practical domain. Deliberate interventions in planetary systems other than the Earth.	Terraforming other planets or satellites (Symes 2023, 2024b)

[156] "Solar radiation management (SRM) methods: which reduce the net incoming short-wave (ultra-violet and visible) solar radiation received, by deflecting sunlight, or by increasing the reflectivity (albedo) of the atmosphere, clouds or the Earth's surface." (Shepherd & WGGC, 2009, p. 1).

[157] "Solar Radiation Management (SRM) refers to the intentional modification of the Earth's shortwave radiative budget with the aim to reduce climate change according to a given metric (e.g., surface temperature, precipitation, regional impacts, etc). Artificial injection of stratospheric aerosols and cloud brightening are two examples of SRM techniques. Methods to modify some fast-responding elements of the longwave radiative budget (such as cirrus clouds), although not strictly speaking SRM, can be related to SRM. SRM techniques do not fall within the usual definitions of mitigation and adaptation" (IPCC, 2012, p. 2).

Term	Typical scope	Distinctive exemplary cases
Geoengineering and synonyms (e.g. climate intervention, climate engineering, Earth system engineering)	Wide scope: typically refers to "non-climate" technological or other deliberate interventions alongside "climate" interventions capable of modifying the Earth system	Harper-Bosch process for fixing nitrogen industrially (Morton 2016), Anthropocene (Crutzen 2006b, Morton 2016)), planetary boundaries (van Vuuren et al 2025)
	Intermediate scope: typically refers to SRM, CDR but also to other deliberate interventions in the Earth climate system	Glacier Stabilization, Inland Sea Reflooding (Symes 2024b, ARC 2025)
	Narrow scope: typically refers to SRM & CDR deliberate interventions in the Earth climate systems	Stratospheric aerosol injection (SAI), iron fertilization (Shepherd & WGCC 2009, IPCC 2012)
Weather modification[158]	Non-geoengineering lower practical domain. Deliberate interventions of the weather	Mitigating extreme heat waves, droughts and hurricanes, preserving fragile ecosystems and biodiversity (Symes 2023, 2024b)
"Unintentional" geoengineering	"Non-deliberate", "accidental", "inadvertent" geoengineering: includes analog physical events to SRM and associated climatic effects of deliberated interventions with "non-climatic" main aims	Natural volcanic eruptions, IMO 2020 regulation of ship pollution (Yuan et al. 2024, Carrington 2024), aviation contrails that trap heat (Poll 2024)

2.B.2. Unintentional geoengineering: improper uses of the term geoengineering relative to the definitions of the Royal Society and IPCC

The importance of the IPCC (2012) and Royal Society (2009) definitions of geoengineering (similar narrow scope but compatible with intermediate scope) explicitly distinguishing between deliberate and non-deliberate or unintentional interventions, main aim and associated effects, and merely physical or physical-intentional stances or points of view of similar objects or systems comes from the fact that the term geoengineering is also used in the literature to refer to either to "unintentional" physical events in the Earth system analog to SRM (e.g., volcanic eruptions are the Earth's geoengineering experiments) or unintended associated effects of deliberate interventions (e.g., climate change as "inadvertent geoengineering", "accidental geoengineering", "inadvertent geoengineering experiment" (Yuan et al., 2024; Carrington, 2024) or "passive climate intervention experiments" (Symes, 2024b)[159].

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[158] As the IPCC neutral definition in the pre-AR6 glossary states explicitly, weather modification interventions are out of the scope of geoengineering but acknowledges there is an unclear or fuzzy boundary.

[159] This also happens with associated terms such as experiment, like in "natural experiment", related to volcanos, or "passive experiments" (Symes, 2024b).

For example, it has been noted early on in the literature of geoengineering research that some public health interventions aimed at diminishing air pollution may have an associated effect of increasing mean global temperature (Crutzen, 2006a). An exemplary case in the scientific literature of the use of the term geoengineering to refer to these unintended associated effects of large-scale deliberate interventions refers to the consequences of new International Maritime Organization (IMO) regulations[160].

The same exemplary case of "non-deliberate", "inadvertent" geoengineering is also captured in the news reporting on this article:

> *IMO2020 anti-pollution policy as an exemplary case of non-deliberate geoengineering in the news. "*Yuan said years of shipping pollution followed by a sharp cut was an accidental large-scale experiment: "We did inadvertent geoengineering for 50 or 100 years over the ocean." (Carrington, 2024).

Finally, Symes (2024b) refers to the IMO2020 exemplary case as "conducting *passive* climate intervention experiments" (emphasis added), not using the term geoengineering but the term climate intervention sometimes used as a synonym in scope (NASEM, 2021).

This "unintentional" or "non-deliberate" geoengineering is an improper use of the term geoengineering relative to relative to the definitions of the Royal Society and IPCC and comes with important trade-offs, particularly the risks of confusion that such use may generate against the economy of language or useful rhetorical function or the reference to analog physical processes to compare with deliberate SRM climate interventions (Royal Society, 2025).

2.C. The life cycle of SRM

Authoritative reports on ethics and governance of SRM distinguish ethical issues between different stages of the life cycle of an intervention (e.g. EGE, 2024) or activities (UNEP, 2023b) (see Table 2.C.1). If authorities are responsible for governing the end product and its consequences, that is, large-scale SRM climate interventions, from a practical point of view, they should also have responsibility for governing the means or enablers of that end product that may come in smaller scales, both research and non-research experiments[161].

Table 2.C.1. Comparison of EGE (2024) four main stages of SRM life cycle with UNEP (2023) three main SRM activities related to ethics and governance of SRM, including SRM research.

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[160] *IMO2020 exemplary case of non-deliberate geoengineering in scientific literature*. "On January 1, 2020, new International Maritime Organization (IMO) regulations on the sulfur content of international shipping fuel took effect … [and] reduced the maximum sulfur content from 3.5% to 0.5%. While IMO2020 is intended to benefit public health by decreasing aerosol loading … IMO2020 effectively represents [...] [an] *inadvertent geoengineering experiment* through a reverse MCB [marine cloud brightening], i.e., marine cloud dimming through reducing cloud droplet number concentration … " (Yuan et al., 2024, emphasis added, edited).

[161] See Carbajal et al. (2025) for an in-depth discussion.

EGE (2024) four main stages of SRM life cycle	UNEP (2023b) three main SRM activities
1) regulating lab-based and other research, e.g. model simulations, that aims to test or deploy SRM (excluding basic research that is foundational for an entire field rather than being SRM-specific); 2) regulating small-scale outdoor experimentation; 3) taking decisions on whether and (if so, under what conditions) to carry out large-scale experimentation or deployment of SRM; and 4) managing the consequences that could emerge after deployment, including how to react if 'rogue' countries use SRM against the global consensus. (EGE, 2024, p. 8)	1. Indoor SRM research[162] 2. Small scale outdoor experiments 3. Large-scale operational SRM deployment (UNEP, 2023b, p. 24)

The life cycle or different stages of SRM interventions are useful to understand the scope of the term SRM in different activities that are connected (e.g. lab research, climate modelling, small-scale outdoor research, large-scale experimentation) and scales (e.g. small, large). Although some authoritative reports emphasize large-scale interventions in their definitions of SRM (e.g. Shepherd & WGGC, 2009) and the concept of climate intervention implies in itself a large-scale intervention (as opposed to weather intervention), our reconstructed scope of SRM includes the concept of life cycle to capture all SRM relevant activities in their appropriate scales.

Incidentally, there is a risk in the SRM literature of interpreting EGE's stages 1 to 3, as interacting in a linear way instead as a network of information and knowledge (Kimmelman & London, 2015), and assign risks also linearly from activities with less risk (1) to more risk (3) (Galbraith, 2021). For example, climate modelling is typically perceived as less risky than other stages such as small outdoor research or large-scale experimentation and hence it does not fall within the ban or "non-use" proposals (Biermann et al., 2022). However, a world with only SRM climate modelling (stage 1 above) without appropriate empirical feedback from small-scale outdoor research (stage 2 above) or large-scale experimentation (stage 3 above), is riskier all other things considered equal because the climate models can still be used for deployment (stage 3 and 4 above), for example in emergency situations, but with less well developed climate models and more physical uncertainties[163].

2.D. Ethical justification of SRM

2.D.1 Jamieson (1966) ethical justification of intentional climate change (ICC)

[162] This include "theoretical analyses, estimates of SRM effectiveness and costs, climate model simulations of SRM approaches, assessments of the impacts of SRM approaches, model evaluation using volcanic and ship-track analogies, laboratory studies of potential injection materials and their reactivities, injector development and social science and humanities research" (UNEP, 2023b, 24).

[163] This argument is based on epistemic reason or values. For a similar argument based on non-epistemic values see Galbraith (2021).

One of the earliest attempts to present an explicit ethical justification of SRM is Jamieson (1996)[164]. Jamieson's primary conclusion based on his principled argument is what he regards as a consensus view that "geoengineer the climate" or do intentional climate change (ICC) is ethically impermissible at the moment of writing the paper. The secondary conclusion is that research on geoengineering or ICC, including what will be regarded as SRM, is ethically permissible if it is carried out following principles and ethical considerations outlined in his argument (also referred to as "ethical and social issues"). The positive case for geoengineering or ICC rests on the following four principles: (1) technical feasibility of ICC interventions, (2) reliable scientific predictability of ICC scenario, (3) social and economic preferability of ICC scenario, (4) non serious and systematic violation of well funded ethical principles or considerations, including (4.1) democratic-decision making, (4.2) prohibition against irreversible environmental changes, (4.3) learning to live with nature (non-domination, non-arrogance).

Early analysis of ethical permissibility of intentional climate change, such as interventions falling under the label of geoengineering or SRM, distinguish between two different activities, deployment and research on intentional climate change (Jamieson, 1996). Of importance, the main reason for ethical permissibility of SRM research[165] is the argument of the lesser of two evils. According to Jamieson, the Earth system may reach a point where deployment of SRM may be the lesser of two evils coupled with the idea that responsible research may imply potential benefits under such a scenario. These potential benefits are two-fold and express themselves in the typical output of responsible research programs, that is, negative and positive findings. According to Jamieson, research allows us to weed out the worst ideas through scientific publication and subsequent review (and discussion) and thus gives us options and capabilities to respond to dire and unexpected situations.

As of December 2025, almost 30 years later, little has changed in the structure of ethical analysis: the main analysis of prohibition of deployment and permissibility of SRM research remains. Unfortunately, the case for the lesser of two evils has been growing stronger. As Antonio Guterres, the head of the UN head publicly recognized, humanity has practically missed the 1.5°C climate target, and that he hopes the overshoot to be "as short as possible and as low in intensity as possible to avoid tipping points" (Watts & Xipai, 2025).

2.D.2. Royal Society (2009) justification of SRM deployment

In 2009, the Royal Society considered SRM's ethical justification within its general justification of geoengineering. In case of global failure to make sufficient progress on mitigation, it considered large-scale deliberate manipulation to the Earth climate system not a substitute for climate change mitigation but as an addition to the portfolio of actions to respond to climate change threats or negative impacts, if there are SRM interventions that are safe, effective and affordable. This justifies a narrow end or main aim of SRM. In turn, the Royal Society introduces a justification for SRM research as means to "investigate whether low risk methods [including SRM interventions] can be made available if it becomes necessary to reduce the rate of warming this century" (Shepherd & WGGC, 2009, p. 57, edited).

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[164] His paper was developed while being a visitor in the Environmental and Societal Impacts Group (ESIG) at the US National Center for Atmospheric Research (NCAR), and an earlier version of the paper was presented as part of the AAAS Symposium on Geoengineering Climate, held in San Francisco in 1994 (Jamieson, 1996).

[165] For simplicity, I will present the argument in terms of SRM but the original scope includes any form of "intentional climate change", geoengineering, climate engineering or climate intervention.

SRM interventions' life cycle including research and potential deployment, should be governed not only by technical principles, but also ethical and governance principles. Specifically related to SRM, the best case scenario for its ethical justification as a short-term limited use as backup to mitigation policies (including CDR) for rapid reduction of global temperatures (scale of decades) with appropriate discontinuation in due course, and not as permanent intervention in the Earth climate system due to uncertainties related to unknown associate effects[166].

It is important to reconstruct the Royal Society's most probable intended scope for SRM interventions to understand the scope of its ethical justification. This methodological ethical principle should be generalized to make proper charitable interpretation and avoid errors or confusions. In the case of the 2009 Royal Society report, this scope focus on stratospheric aerosol injection (SAI) or marine cloud brightening (MCB) as exemplary cases of reflectivity of short wave solar radiation but did not include climate interventions that tried to modify emissivity of long-wave radiation (e.g. cirrus cloud thinning CCT, or contrail management, CM)[167].

2.E. Abandonment of the term geoengineering in the current authoritative reports on SRM

The term geoengineering, originally used in the policy report of the Royal Society (2009) and the IPCC (2012) in their neutral definitions, was associated with a negative connotation from early on, especially in the community of climate scientists and environmentalists (Jamieson, 2014; Singer, 2016; Morton, 2016). Currently, the term geoengineering has been either replaced in recent authoritative reports and ethical guidelines by alternative umbrella terms with more neutral attitudinal connotation such as climate engineering (COMEST, 2023) or climate interventions (e.g. AGU [Williams et al.] 2024; NASEM, 2021) but with a similar scope. Because of the different characteristics and risk-benefit profiles of the two main categories, CDR & SRM, they have been analyzed separately (e.g. EGE, 2024; Royal Society, 2025). Jamieson (2014) partly anticipated and justified these changes and the subsequent abandonment of the term geoengineering in current authoritative reports based on his terminological analysis

[166] "SRM methods should not be applied unless there is a need to rapidly limit or reduce global average temperatures. Because of uncertainties over side effects and sustainability they should only be applied for a limited period and accompanied by aggressive programmes of conventional mitigation and/or CDR, so that their use may be discontinued in due course." (Shepherd & WGGC, 2009, pp. 58-9).

[167] For example, contrail management (CM) looks to minimize the creation of condensation trails by airplanes, a non-CO_2 contribution to global warming. We could imagine that this type of SRM could be implemented indefinitely as in comparison to SAI or MCB only as temporary. However CM could only contribute to a fraction of the needed global cooling and it does not seem able to replace other SRM interventions such as SAI or MCB.

Annex 3 - Chapter 3[168]

Table 3.1. English language search strategy in PubMed, including keystring used, database searched, number of articles returned and number of relevant articles.

Keystring used	Type of article	Database/search engine searched	Articles returned	Relevant articles
"SRM" OR "Solar*radiation*modification" OR "Solar*geoengineering	Titles OR Abstract OR Topic OR	PubMed	16,768	Following title and abstract checks, 23 deemed relevant. Following full text check, 6 included
"SRM" OR "Solar*radiation*modification" OR "Solar*geoengineering" AND "Health" OR "Public*Health"	Titles OR Abstract OR Topic OR	PubMed	3,676	Following title and abstract checks, 0 deemed, as they had already been included.
"SAI" OR "Stratospheric*aerosol*injection"	Titles OR Abstract OR Topic OR	PubMed	8,396	Following title and abstract checks, 15 deemed relevant. Following full text check, 3 included.

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Keystring used	Type of article	Database/search engine searched	Articles returned	Relevant articles
"SAI" OR "Stratospheric*aerosol*injection" AND "Health" OR "Public*Health"	Titles OR Abstract OR Topic OR	PubMed	2,199	Following title and abstract checks, 0 deemed, as they had already been included.
("geoengineering"[Title/Abstract] OR "solar radiation management"[Title/Abstract] OR "SAI"[Title/Abstract] OR "SRM"[Title/Abstract]) AND ("health"[Title/Abstract] OR "public health"[Title/Abstract] OR "mental health"[Title/Abstract])	Titles OR Abstract OR Topic OR	PubMed(second review from July 2025)	902	Following title and abstract checks, 7 deemed relevant. Following full text check, 0 included.
("geoeng*" OR "solar geoeng*" OR "solar radiation modif*" OR "solar radiation manag*" OR "SRM" OR "climat* intervent*" OR "climat* geoeng*" OR "climat* engin*" OR "climat* cool*" OR "SAI" OR "stratospher* aerosol injection" OR "injection of stratospher* aerosol*" OR "stratospher* injection of reflective particl*" OR "atmosphere* stratospher* aerosol injection" OR "stratospher* aerosol*" OR "sulf* geoeng*") AND ("health*" OR "human health" OR "public health" OR "mental health")	Titles OR Abstract OR Topic OR	PubMed (second review from July 2025)	7,187	After 20 pages with no results, the search was abandoned.

Table 3.2. English language search strategy Google Scholar, including keystring used, database searched, number of articles returned and number of relevant articles.

Keystring used	Type of article	Database/search engine searched	Articles returned	Relevant articles
“Solar* radiation* modification” OR “Solar* geoengineering”	Titles OR Abstract OR Topic OR	Google Scholar	18,300	Following title and abstract checks, 29 deemed relevant. Following full text check, 4 included
“Solar* radiation* modification” OR “Solar* geoengineering” AND “Health” OR “Public* Health”	Titles OR Abstract OR Topic OR	Google Scholar	2,480	Following title and abstract checks, 2 deemed, as they had already been included.
“SAI” OR “Stratospheric* aerosol* injection”	Titles OR Abstract OR Topic OR	Google Scholar	15,400	Following title and abstract checks, 17 deemed relevant. Following full text check, 1 included.
“SAI” OR “Stratospheric* aerosol* injection” AND “Health” OR “Public*Health”	Titles OR Abstract OR Topic OR	Google Scholar	8,900	Following title and abstract checks, 4 deemed, as they had already been included.

Keystring used	Type of article	Database/search engine searched	Articles returned	Relevant articles
("geoeng*" OR "solar geoeng*" OR "solar radiation modif*" OR "solar radiation manag*" OR "SRM" OR "climat* intervent*" OR "climat* geoeng*" OR "climat* engin*" OR "climat* cool*" OR "SAI" OR "stratospher* aerosol injection" OR "injection of stratospher* aerosol*" OR "stratospher* injection of reflective particl*" OR "atmosphere* stratospher* aerosol injection" OR "stratospher* aerosol*" OR "sulf* geoeng*") AND ("health*" OR "human health" OR "public health" OR "mental health")	Titles OR Abstract	Google Scholar (second review from July 2025)	7,050	After 20 pages with no results, the search was abandoned.
"stratospheric aerosol injection" "mental health"	Titles OR Abstract	Google Scholar (second review from July 2025)	107	Following title and abstract checks, 3 deemed relevant. Following full text check, 0 included.

Keystring used	Type of article	Database/search engine searched	Articles returned	Relevant articles
"solar geoengineering" "public health"	Titles OR Abstract	Google Scholar (second review from July 2025)	857	Following title and abstract checks, 6 deemed relevant. Following full text check, 1 included.
"climate intervention" "health"	Titles OR Abstract	Google Scholar (second review from July 2025)	4,640	Following title and abstract checks, 8 deemed relevant. Following full text check, 0 included.

References

Advanced Research and Invention Agency (ARIA). (2024). Exploring Options for Actively Cooling the Earth—Call for Proposals. https://www.aria.org.uk/media/wotbzgsm/aria-actively-cooling-the-earth-programme.pdf

Advanced Research and Invention Agency (ARIA). (2025). Funded projects. Exploring Climate Cooling.https://aria.org.uk/opportunity-spaces/future-proofing-our-climate-and-weather/exploring-climate-cooling/funded-projects

Advanced Research for Climate Emergencies (ARC). (2024). Inland Sea Reflooding. Grants. Preventing Catastrophic Sea Level Rise. https://arc.renaissancephilanthropy.org/project/inland-sea-reflooding/.

Agich, G. J. (2019). Knowing One's Way Around: The Challenge of Identifying and Overseeing Innovations in Patient Care. *The American Journal of Bioethics*, 19(6), 1–3. https://doi.org/10.1080/15265161.2019.1611275.

Ajzen, I., Fishbein, M., Lohmann, S., & Albarracín, D. (2018). The Influence of Attitudes on Behavior. In The Handbook of Attitudes, Volume 1: Basic Principles (2nd Edition, pp. 197–255). Routledge.

Aldy, J., Felgenhauer, T., Pizer, W. A., Tavoni, M., Belaia, M., Borsuk, M. E., Ghosh, A., Heutel, G., Heyen, D., Horton, J., Keith, D., Merk, C., Moreno-Cruz, J. B., Reynolds, J. L., Ricke, K., Rickels, W., Shayegh, S., Smith, W., Tilmes, S., Wagner, G., & Wiener, J. B. (2021). Social science research to inform solar geoengineering. Science, 374(6569), 815–818. https://doi.org/10.1126/science.abj6517.

Alesina, A., & La Ferrara, E. (2002). Who trusts others? Journal of Public Economics, 85(2), 207–234.

American Geophysical Union (AGU). (2024). Ethical framework principles for climate intervention research. https://doi.org/10.22541/essoar.172917365.53105072/v1.

Anderson P. W. (1972). More is different. Science, 177(4047), 393–396. https://doi.org/10.1126/science.177.4047.393.

André, J.-B., Fitouchi, L., Debove, S., & Baumard, N. (2022). An evolutionary contractualist theory of morality. Journal of Theoretical Biology, 552, Artículo 111242. https://doi.org/10.1016/j.jtbi.2022.111242

Andrews, T. M., Delton, A. W., & Kline, R. (2022). Anticipating moral hazard undermines climate mitigation in an experimental geoengineering game. Ecological Economics, 196, 107421. https://doi.org/10.1016/j.ecolecon.2022.107421.

ARIA UK. (2025). ARIA UK. https://www.aria.org.uk/

Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. The Economic Journal, 99(394), 116–131.

Asilomar Scientific Organizing Committee. (2010). The Asilomar conference recommendations on principles for research into climate engineering techniques, 1. http://www.climate.org/PDF/AsilomarConferenceReport.pdf

Bais, A. F., Bernhard, G., McKenzie, R. L., Aucamp, P. J., Young, P. J., Ilyas, M., Jöckel, P., & Deushi, M. (2019). Ozone–climate interactions and effects on solar ultraviolet radiation. Photochemical & Photobiological Sciences, 18(3), 602–640. https://doi.org/10.1039/C8PP90059K

Barnes, J., Dove, M., Lahsen, M., Mathews, A., McElwee, P., McIntosh, R., Moore, F., O'Reilly, J., Orlove, B., Puri, R., Weiss, H., & Yager, K. (2013). Contribution of anthropology to the study of climate change. Nature Climate Change, 3(6), 541-544. https://doi.org/10.1038/nclimate1775 .

Baum, C. M., Fritz, L., Low, S., Brutschin, E., Merk, C., Sovacool, B., Cotorceanu, M., Do, H. T., Goeschl, T., Mangi, A., Merk, L., Román, M., & Siegrist, M. (2024). Public perceptions and support of climate intervention technologies across the Global North and Global South. Nature Communications, 15, 2060. https://doi.org/10.1038/s41467-024-46341-5.

Baum, C. M., Low, S., & Sovacool, B. K. (2022). Between the sun and us: Expert perceptions on the innovation, policy, and deep uncertainties of space-based solar geoengineering. Renewable and Sustainable Energy Reviews, 158, 112179. https://doi.org/10.1016/j.rser.2022.112179

Beck, U. (1999). World Risk Society. London, Polity Press. ISBN: 978-0-745-62221-7.

Bellamy, R., Chilvers, J., & Vaughan, N. E. (2016). Deliberative mapping of options for tackling climate change: Citizens and specialists 'open up' appraisal of geoengineering. Public Understanding of Science, 25(3), 269–286. https://doi.org/10.1177/0963662514548628

Bellamy, R., Chilvers, J., Vaughan, N. E., & Lenton, T. M. (2017). 'Opening up' geoengineering appraisal: Multi-criteria mapping of options for tackling climate change. Global Environmental Change, 44, 133–147. https://doi.org/10.1016/j.gloenvcha.2017.03.013

Besley, J. C. (2010). Public engagement and the impact of fairness perceptions on decision favorability and acceptance. Science Communication, 32(2), 256–280.

Biermann, F. (2023). Mexico Bans Solar Geoengineering Experiments. Frank Biermann. https://www.frankbiermann.org/post/mexico-bans-solar-geoengineering-experiments

Biermann, F., & Gupta, A. (2024). A paradigm shift? African countries call for the non-use of solar geoengineering at UN Environment Assembly. PLOS Climate, 3(5), e0000413. https://doi.org/10.1371/journal.pclm.0000413

Biermann, F., Oomen, J., Gupta, A., Ali, S. H., Conca, K., Hajer, M. A., Kashwan, P., Kotzé, L. J., Leach, M., Messner, D., Okereke, C., Persson, Å., Potočnik, J., Schlosberg, D., Scobie, M., & VanDeveer, S. D. (2022). Solar geoengineering: The case for an international non-use agreement. WIREs Climate Change, 13(3), e754. https://doi.org/10.1002/wcc.754

Binmore, K., Rubinstein, A., & Wolinsky, A. (1985). The Nash bargaining solution in economic modelling. The RAND Journal of Economics. https://doi.org/10.2307/2555382

Bipartisan Policy Center. (2011). Task Force on Climate Remediation Research. https://bipartisanpolicy.org/report/task-force-on-climate-remediation-research/

Bodansky, D. (2013). The who, what, and wherefore of geoengineering governance. Harvard Project on Climate Agreements Working Paper. https://cdrlaw.org/wp-content/uploads/2020/09/Bodansky-who-what.pdf

Boselius, L., Duffey, A., & Irvine, P. J. (2025). Peak shaving with solar radiation modification would shorten global temperature overshoot. Oxford Open Climate Change, *5*(1), kgaf013. https://doi.org/10.1093/oxfclm/kgaf013

Boucher, O., Kleinschmitt, C., & Myhre, G. (2017). Quasi-Additivity of the Radiative Effects of Marine Cloud Brightening and Stratospheric Sulfate Aerosol Injection. Geophysical Research Letters, 44(21). https://doi.org/10.1002/2017GL074647

Bourque, F., & Willox, A. C. (2014). Climate change: the next challenge for public mental health? International Review of Psychiatry, 26(4), 415–422. https://doi.org/10.3109/09540261.2014.925851

Brent, K., Simon, M., & McDonald, J. (2024). From informal to formal governance of solar radiation management. Climate Policy, 25(6), 947–964. https://doi.org/10.1080/14693062.2024.2430688

Buck, H. J. (2018). Perspectives on solar geoengineering from Finnish Lapland: Local insights on the global imaginary of Arctic geoengineering. Geoforum, 91, 78–86. https://doi.org/10.1016/j.geoforum.2018.02.018

Buck, H. J. (2019). After Geoengineering: Climate Tragedy, Repair, and Restoration. Verso.

Buck, H. J., Shah, P., Yang, J. Z., & Arpan, L. (2025). Public concerns about solar geoengineering research in the United States. Communications Earth & Environment, 6(1), 609. https://doi.org/10.1038/s43247-025-02595-5

Buedo, P., & Daly, T. (2024). A contextual understanding of the high prevalence of depression in Latin America. The Lancet Regional Health - Americas, 32, 100717. https://doi.org/10.1016/j.lana.2024.100717

Burns, E. T., Flegal, J. A., Keith, D. W., Mahajan, A., Tingley, D., & Wagner, G. (2016). What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for future research. Earth's Future, 4(11), 536–542. https://doi.org/10.1002/2016EF000461

Caldeira, K., & Ricke, K. (2013). Prudence on solar climate engineering. Nature Climate Change, 3(11), 941–943. https://doi.org/10.1038/nclimate2036

Callon, M., Lascoumes, P., & Barthe, Y. (2001). Agir dans un monde incertain. Essai sur la démocratie technique. Seuil.

Camilloni, I., Montroull, N., Gulizia, C., & Saurral, R. I. (2022). La Plata Basin hydroclimate response to solar radiation modification with stratospheric aerosol injection. Frontiers in Climate, 4, 763983. https://doi.org/10.3389/fclim.2022.763983

Cao, L., Duan, L., Bala, G., & Caldeira, K. (2017). Simultaneous stabilization of global temperature and precipitation through cocktail geoengineering. Geophysical Research Letters, 44(14), 7429–7437. https://doi.org/10.1002/2017GL074281

Carabajal, M. I., Santi, M. F., Rodríguez Garat, C., Lisanti, G. F., Nasi, J., Daly, T., Mastroleo, I., Luna, F., & Camilloni, I. (2025). No Governance Is Governance: Mapping Solar Geoengineering Discussions in Latin America & the Caribbean. European Journal of Risk Regulation, 1–17. doi:10.1017/err.2025.10025

Carlino, H., Gogorza, A., & Carlino, M. (2024). Strengthening regional capacities to address the risk of and from overshooting 1.5°C global warming in Latin America and the Caribbean. C2G/ECLAC. https://www.cepal.org/en/publications/80737-strengthening-regional-capacities-address-risk-and-overshooting-15degc-global

Carlson, C. J., Colwell, R., Hossain, M. S., Rahman, M. M., Robock, A., Ryan, S. J., Alam, M. S., & Trisos, C. H. (2022). Solar geoengineering could redistribute malaria risk in developing countries. Nature Communications, 13(1), 2150. https://doi.org/10.1038/s41467-022-29613-w

Carnegie Climate Governance Initiative. (2020). Evidence brief: Governing solar radiation modification. https://www.c2g2.net/wp-content/uploads/c2g_evidencebrief_SRM.pdf

Carrington, D. (2024, May 30). ‘Termination shock’: Cut in ship pollution sparked global heating spurt. *The Guardian*. https://www.theguardian.com/environment/article/2024/may/30/termination-shock-cut-in-ship-pollution-sparked-global-heating-spurt

Carvalho, A., & Riquito, M. (2022). “It’s just a Band-Aid!”: Public engagement with geoengineering and the politics of the climate crisis. Public Understanding of Science, 31(7), 903–920. https://doi.org/10.1177/09636625221095353

Chalmers, D. (2020). What is Conceptual Engineering and What Should It Be? Inquiry: An Interdisciplinary Journal of Philosophy, 63. https://doi.org/10.1080/0020174x.2020.1817141

Chalmin, A. (2024). Global southwashing: How The Degrees Initiative is imposing its solar geoengineering agenda onto climate research in the Global South. Geoengineering Monitor. https://www.geoengineeringmonitor.org/the-degrees-initiative

Charlson, F., Ali, S., Benmarhnia, T., Pearl, M., Massazza, A., Augustinavicius, J., & Scott, J. G. (2021). Climate Change and Mental Health: A Scoping Review. International Journal of Environmental Research and Public Health, 18(9), 4486. https://doi.org/10.3390/ijerph18094486

Chhetri, N., Chong, D., Conca, K., Falk, R., Gillespie, A., Gupta, A., Jinnah, S., Lee, J. R., Li, S., McKinnon, C., Mitchell, R., Nicholson, S., Rayner, S., Sarewitz, D., Shrum, W., Stephens, J., & Surprise, K. (2018). Governing solar radiation management: Academic working group on climate engineering governance (Forum for Climate Engineering Assessment Report).

American University. https://ceassessment.org/reports-and-publications/

City of Alameda Legislative Portal. (2024b). Agenda & minutes related to MCB item. https://alameda.legistar.com/

City of Alameda. (2024a). City response to questions regarding the Marine Cloud Brightening Project. https://www.alamedaca.gov/News/City-responds-to-questions-regarding-the-Marine-Cloud-Brightening-Project

Commission on the Ethics of Scientific Knowledge and Technology (COMEST). (2023). Report of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) on the ethics of climate engineering (SHS/COMEST-13/2023/1 REV.). UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000386677

Convention on Biological Diversity (CBD). (2010). Decision X/33: Biodiversity and climate change. https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-33-en.pdf

Convention on Biological Diversity (CBD). (2012). Decision XI/20: Climate-related geoengineering. https://www.cbd.int/doc/decisions/cop-11/cop-11-dec-20-en.pdf

Corner, A., & Pidgeon, N. (2015). Like artificial trees? The effect of framing by natural analogy on public perceptions of geoengineering. Climatic Change, 130(3), 425–438. https://doi.org/10.1007/s10584-014-1148-6

Corry, O., McLaren, D., & Kornbech, N. (2024). Scientific models versus power politics: How security expertise reframes solar geoengineering. *Review of International Studies*, 1–20. https://doi.org/10.1017/S0260210524000482

Cosh, S. M., Ryan, R., Fallander, K., Robinson, K., Tognela, J., Tully, P. J., & Lykins, A. D. (2024). The relationship between climate change and mental health: a systematic review of the association between eco-anxiety, psychological distress, and symptoms of major affective disorders. BMC Psychiatry, 24(1), 833. https://doi.org/10.1186/s12888-024-06274-1

Crutzen, P. J. (2006a). Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma? Climatic Change, 77(3–4), 211. https://doi.org/10.1007/s10584-006-9101-y

Crutzen, P. J. (2006b). The “Anthropocene.” En E. Ehlers & T. Krafft (Eds.), Earth System Science in the Anthropocene (pp. 13–18). Springer. https://doi.org/10.1007/3-540-26590-2_3

Curry, O. S. (2016). Morality as cooperation: A problem-centred approach. InThe Evolution of Morality (pp. 27–51). Springer.

Daly, T., & Mastroleo, I. (2025). Use of unproven interventions in clinical practice in the Declaration of Helsinki 2024: Building on welcome changes. Theoretical Medicine and Bioethics. https://doi.org/10.1007/s11017-025-09725-2

Dannenberg, A., & Zitzelsberger, S. (2019). Climate experts’ views on geoengineering depend on their beliefs about climate change impacts. Nature Climate Change, 9, 769–775. https://doi.org/10.1038/s41558-019-0564-z

Davies, G., & Vinders, J. (2025). Geoengineering, the precautionary principle, and the search for climate safety. European Journal of Risk Regulation. 16(4), 1223–1234. https://doi.org/10.1017/err.2025.14

Degrees NGO. (2025). Degrees NGO. https://www.degrees.ngo/

Dennett, D. C. (1989). The Intentional Stance. MIT Press.

Diffenbaugh, N. S., & Barnes, E. A. (2023). Data-driven predictions of the time remaining until critical global warming thresholds are reached. Proceedings of the National Academy of Sciences, 120(6), e2207183120. https://doi.org/10.1073/pnas.2207183120

Dinner, I., Johnson, E. J., Goldstein, D. G., & Liu, K. (2011). Partitioning default effects: Why people choose not to choose. Journal of Experimental Psychology, 17(4), 332.

Dove, Z., Jinnah, S., & Talati, S. (2024). Building capacity to govern emerging climate intervention technologies. Elementa: Science of the Anthropocene, 12(1), 00124. https://online.ucpress.edu/elementa/article/12/1/00124/202924/

Dykxhoorn, J., Fischer, L., Bayliss, B., Brayne, C., Crosby, L., Galvin, B., Geijer-Simpson, E., Jones, O., Kaner, E., Lafortune, L., McGrath, M., Moehring, P., Osborn, D., Petermann, M., Remes, O., Vadgama, A., & Walters, K. (2022). Conceptualising public mental health: development of a conceptual framework for public mental health. BMC Public Health, 22(1), 1407. https://doi.org/10.1186/s12889-022-13775-9

Eagly, A. H., & Chaiken, S. (1993). Psychology of Attitudes. Wadsworth Publishing.

Eastham, S. D., Keith, D. W., & Barrett, S. R. H. (2018). Mortality tradeoff between air quality and skin cancer from changes in stratospheric ozone. Environmental Research Letters, 13(3), 034035.

Eastham, S. D., Weisenstein, D. K., Keith, D. W. & Barrett, S. R. (2018). Quantifying the impact of sulfate geoengineering on mortality from air quality and UV-B exposure. Atmospheric Environment, 187, 424–434.

Effiong, U., & Neitzel, R. L. (2016). Assessing the direct occupational and public health impacts of solar radiation management with stratospheric aerosols. Environmental Health: A Global Access Science Source, 15(1), Article 7. https://doi.org/10.1186/s12940-016-0089-0

Elster, J. (1984). Ulysses and the Sirens: Studies in rationality and irrationality (Rev. ed). Cambridge University Press.

Environmental Defense Fund. (2025). Environmental Defense Fund. https://www.edf.org/

ETC Group. (2025). ETC Group. https://www.etcgroup.org/

European Commission, Group of Chief Scientific Advisors (GCSA). (2024). Scientific Opinion on Solar Radiation Modification. https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/scientific-opinion-solar-radiation-modification_en

European Environment Agency. (2024). Governance in complexity: Sustainability governance under highly uncertain and complex conditions (EEA Report No. 05/2024). https://doi.org/10.2800/597121

European Group on Ethics in Science and New Technologies (EGE). (2024). Opinion on solar radiation modification: Ethical perspectives. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/951016

Felgenhauer, T., Bala, G., Borsuk, M., Camilloni, I., Wiener, J., & Xu, J. (2025). Practical paths to risk–risk analysis of solar radiation modification. Global Environmental Change, 84, 102039. https://doi.org/10.1093/oxfclm/kgaf012

Fotion, N. (2014). Exceptions Theory in N. Fotion (Ed.), Theory vs. Anti-Theory in Ethics: A Misconceived Conflict. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199373529.003.0007

Fritz, L., Baum, C. M., Low, S., & Sovacool, B. K. (2024). Public engagement for inclusive and sustainable governance of climate interventions. Nature Communications, 15(1), 4168. https://www.nature.com/articles/s41467-024-48510-y

Fritz, L., Baum, C., Brutschin, E., Low, S., & Sovacool, B. (2024). Climate beliefs, climate technologies and transformation pathways: Contextualizing public perceptions in 22 countries. Global Environmental Change, 87, 102880. https://doi.org/10.1016/j.gloenvcha.2024.102880

Frosch, R. A. (2009). Geoengineering: What, how, and for whom? Physics Today, 62(2), 10–12. https://doi.org/10.1063/1.3086081

Funtowicz, S. & Ravetz, J. (1993). Science for the post-normal age, Futures, Volume 25, Issue 7, 1993, Pages 739-755, ISSN 0016-3287, https://doi.org/10.1016/0016-3287(93)90022-L.

Funtowicz, S., & Hidalgo, C. (2008). Ciencia y política con la gente en tiempos de incertidumbre, conflicto de intereses e indeterminación. En J. A. López Cerezo & F. J. Gómez González (Eds.), Apropiación social de la ciencia (pp. 193–214). Biblioteca Nueva.

Galbraith, J. (2021). Values in early-stage climate engineering: The ethical implications of "doing the research". Studies in History and Philosophy of Science, 86, 103–113. https://doi.org/10.1016/j.shpsa.2021.01.009

García, R. (2006). Sistemas complejos: Conceptos, método y fundamentación epistemológica de la investigación interdisciplinaria. Gedisa.

Gardiner, S. M., & Fragnière, A. (2018). The Tollgate Principles for the governance of geoengineering. Ethics, Policy & Environment, 21(2), 143–174. https://doi.org/10.1080/21550085.2018.1448039

GBD 2023 Demographics Collaborators. (2025). Global age-sex-specific all-cause mortality and life expectancy estimates for 204 countries and territories and 660 subnational locations, 1950-2023: a demographic analysis for the Global Burden of Disease Study 2023. The Lancet, 406(10513), 1731–1810. https://doi.org/10.1016/S0140-6736(25)01330-3

Geoengineering Monitor. (2025). *Key Reasons to Oppose Geoengineering*. Retrieved December 16, 2025, from https://www.geoengineeringmonitor.org/reasons-to-oppose

Ghirga, G. (2025). Potential mental health risks associated with stratospheric aerosol injection methods using aluminum oxide. En M. Beech (Ed.), Geoengineering and climate change: Methods, risks, and governance (pp. 91–95). Wiley. https://doi.org/10.1002/9781394204847.ch6

GM Nation? (2003). The findings of the public debate. Department of Trade and Industry.

Gracia, D. (2013). Práctica clínica e investigación clínica. In R. Dal-Ré, X. Carné, & D. Gracia (Eds.), Luces y sombras en la investigación clínica (pp. 39–55). Triacastela.

Gray, K., Waytz, A., & Young, L. (2012). The moral dyad: A fundamental template unifying moral judgment. Psychological Inquiry, 23(2), 206–215.

Great Barrier Reef Foundation. (n.d.). What is cloud brightening? https://www.barrierreef.org/news/explainers/what-is-cloud-brightening

Green Alliance. (2000). Steps into Uncertainty: Handling risks and uncertainty in environmental policy-making. Green Alliance.

Gross, C. (2007). Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance. Energy Policy, 35(5), 2727–2736.

Grove-White, R., Macnaghten, P., & Wynne, B. (2000). Wising Up: The Public and New Technologies. Centre for the Study of Environmental Change (CSEC), Lancaster University.

Grove-White, R., Macnaghten, P., Mayer, S., & Wynne, B. (1997). Uncertain World: Genetically Modified Organisms, Food and Public Attitudes in Britain. Centre for the Study of Environmental Change (CSEC), Lancaster University.

Guivant, J. S. (2005). A governança dos riscos e os desafios para a redefinição da arena pública no Brasil. En Ciência, tecnologia e sociedade: Novos modelos de governança (pp. 47–85). Centro de Gestão e Estudos Estratégicos.

Guivant, J. S., & Fromer, M. (2023). Interdisciplinaridade Na Pesquisa Sobre Mudança Climática: O Caso Do Inct-Mc Fase 2. En A. Autran & T. Andrade (Orgs.), Qual Interdisciplinaridade está em jogo?. Pontes Editora.

Guivant, J. S., & Macnaghten, P. (2011). Breaking the consensus: a perspective on technological governance from Brazil. En T. Zülsdorf et al. (Eds.), Quantum Engagements: Social Reflections of Nanoscience and Emerging Technologies (pp. 109–121). Akademische Verlagsgessellchaft AKA GmbH.

Guston, D. H. (2014). Understanding 'anticipatory governance'. Social Studies of Science, 44(2), 218–242. https://doi.org/10.1177/0306312713508669

Guzmán, R. A., Barbato, M. T., Sznycer, D., & Cosmides, L. (2022). A moral trade-off system produces intuitive judgments that are rational and coherent and strike a balance between conflicting moral values. Proceedings of the National Academy of Sciences, 119(42), e2214005119.

Haidt, J. (2013). The righteous mind. Penguin Books.

Hands Off Mother Earth! (2025). Hands Off Mother Earth! https://handsoffmotherearth.org/

Harding, A., Keith, D., Yang, W., & Vecchi, G. (2024). Impact of Solar Geoengineering on Temperature-Attributable Mortality. Proceedings of the National Academy of Sciences, 121(52), e2401801121. https://doi.org/10.1073/pnas.2401801121

Hartinger, S. M., et al. (2024). The 2023 Latin America report of the Lancet Countdown on health and climate change: the imperative for health-centred climate-resilient development. The Lancet Regional Health - Americas, 33, 100746. https://doi.org/10.1016/j.lana.2024.100746

Hartinger, S. M., et al. (2025). The 2025 *Lancet* Countdown Latin America report: moving from promises to equitable climate action for a prosperous future. *The Lancet Regional Health – Americas*, *52*, Article 101276. https://doi.org/10.1016/j.lana.2025.101276

Harvard University, Salata Institute. (2024). An Update on SCoPEx. https://salatainstitute.harvard.edu/an-update-on-scopex/

Hastrup, K. (2013). Anthropological contributions to the study of climate: Past, present, future. WIREs Climate Change, 4(4), 269–281. https://doi.org/10.1002/wcc.219

Heinrich Böll Foundation. (2025). Heinrich Böll Foundation. https://www.boell.de/en

Hendriks, C. M. (2016). Coupling citizens and elites in deliberative systems: The role of institutional design. European Journal of Political Research, 55, 43–60. https://doi.org/10.1111/1475-6765.12123

Heyward, C., & Rayner, S. (2013). A Curious Asymmetry: Social Science Expertise and Geoengineering.

Hopster, J. (2021). What are Socially Disruptive Technologies? Technology in Society, 67, 101750. https://doi.org/10.1016/j.techsoc.2021.101750

Horton, J. B. (2015). Liability for solar geoengineering. NYU Environmental Law Journal, 23, 225–273. https://www.nyuelj.org/wp-content/uploads/2015/02/Horton_READY_FOR_WEBSITE.pdf

House of Commons Science and Technology Committee. (2010). The Regulation of Geoengineering. https://publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/221.pdf

Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (Eds.). (2021). Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 2897–2930). Cambridge University Press. https://doi.org/10.1017/9781009157896.031

Hubert, A.-M. (2017). Code of conduct for responsible geoengineering research. University of Calgary. https://www.ucalgary.ca/sites/default/files/teams/463/revised-code-of-conduct-for-geoengineering-research-2017-hubert.pdf.

Hussain, A., Latif, M., Shoaib, M., & Khan, V. (2025). Projected malaria transmission risk under climate intervention in South Asia. Environmental Research Communications, 7(3), 035020. https://doi.org/10.1088/2515-7620/adbeb9

Hussain, A., Sipra, H. F. K., Waheed, A., & Ukhurebor, K. E. (2024). Exploring the academic perceptions of climate engineering in developing countries. *Atmósfera*, *38*, 53264. Epub 05 de febrero de 2024. https://doi.org/10.20937/atm.53264

Intergovernmental Panel on Climate Change (IPCC) Working Group II. (2022). Summary for Policymakers (AR6 WGII). https://www.ipcc.ch/report/ar6/wg2/chapter/summary-for-policymakers/

Intergovernmental Panel on Climate Change (IPCC) Working Group III. (2022). Carbon Dioxide Removal (CDR) Factsheet (AR6). https://www.ipcc.ch/report/ar6/wg3/downloads/outreach/IPCC_AR6_WGIII_Factsheet_CDR.pdf

Intergovernmental Panel on Climate Change (IPCC). (2012). Meeting report of the Intergovernmental Panel on Climate Change expert meeting on geoengineering (IPCC Working Group III Technical Support Unit). Potsdam Institute for Climate Impact Research. https://archive.ipcc.ch/pdf/supporting-material/EM_GeoE_Meeting_Report_final.pdf

Intergovernmental Panel on Climate Change (IPCC). (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5-WG1). Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/

Intergovernmental Panel on Climate Change (IPCC). (2014a). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5-WG2). Cambridge University Press. https://www.ipcc.ch/report/ar5/wg2/

Intergovernmental Panel on Climate Change (IPCC). (2014b). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5-WG3). Cambridge University Press. https://www.ipcc.ch/report/ar5/wg3/

Intergovernmental Panel on Climate Change (IPCC). (2014c). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5-SYR). IPCC. https://www.ipcc.ch/report/ar5/syr/

Intergovernmental Panel on Climate Change (IPCC). (2018). Global Warming of 1.5 °C: An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways (SR15). IPCC. https://www.ipcc.ch/sr15/

Intergovernmental Panel on Climate Change (IPCC). (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC). IPCC. https://www.ipcc.ch/srocc/

Intergovernmental Panel on Climate Change (IPCC). (2021). Annex VII: Glossary. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 2215–2256) (AR 6). Cambridge University Press. https://doi.org/10.1017/9781009157896.022

Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change 2023: Synthesis. [Institutional report]. Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115 https://doi.org/10.59327/IPCC/AR6-9789291691647 .

International Institute for Sustainable Development (IISD). (2019). Earth Negotiations Bulletin: OECPR-4 / UNEA-4 Daily Coverage & Summary. https://enb.iisd.org/unep/oecpr4-unea4

Irvine, P., & Samuels-Crow, K. (2024). What Is SRM? SRM360. https://srm360.org/article/what-is-srm/

Irwin, A., & Wynne, B. (1996). 'Introduction' in A. Irwin, & B. Wynne (eds) Misunderstanding Science? pp. 1-17. Cambridge: Cambridge University Press. https://www.cambridge.org/core/books/misunderstanding-science/2BD57300C7190D3B1D8E1E67E074F895

Irwin, T. H. (1981). Homonymy in Aristotle. The Review of Metaphysics, 34(3), 523–544.

Jacob, D. J., & Winner, D. A. (2009). Effect of climate change on air quality. Atmospheric Environment, 43(1), 51–63.

Jamieson, D. (1996). Ethics and intentional climate change. Climatic Change, 33(3), 323–336. https://doi.org/10.1007/BF00142580

Jamieson, D. (2014). Reason in a Dark Time: Why the Struggle Against Climate Change Failed -- and What It Means for Our Future. Oxford University Press.

Jasanoff, S. (2003). Technologies of humility: Citizen participation in governing science. Minerva, 41(3), 223–244. https://doi.org/10.1023/A:1025557512320

Jasanoff, S. (2004). States of knowledge: The co-production of science and the social order. Routledge.

Jasanoff, S. (2005). Designs on Nature: Science and Democracy in Europe and the United States. Princeton University Press.

Jinnah, S., & Dove, Z. (2025). Solar radiation management: A history of the governance and political milestones. Environmental Science: Atmospheres, 5(6), 656–673.

https://doi.org/10.1039/D5EA00008D

Jinnah, S., Nicholson, S., & Flegal, J. (2018). Toward legitimate governance of solar geoengineering research: A role for sub-state actors. Ethics, Policy & Environment, 21(3), 366–381. https://doi.org/10.1080/21550085.2018.1562526

Jinnah, S., Talati, S., Bedsworth, L., Gerrard, M., Kleeman, M., Lempert, R., Mach, K., Nurse, L., Patrick, H. O., & Sugiyama, M. (2024). Do small outdoor geoengineering experiments require governance? Science, 385(6709), 600–603. https://doi.org/10.1126/science.adn2853

Joly, P.-B. (2001). Les OGM entre la science et le public? Quatre modèles pour la gouvernance de l'innovation et des risques. Économie rurale, 266, 11–29. https://doi.org/10.3406/ecoru.2001.5273

Jørgensen, M. L., Anker, H. T., & Lassen, J. (2020). Distributive fairness and local acceptance of wind turbines: The role of compensation schemes. Energy Policy, 138, 111294.

Keith, D. (2013). A Case for Climate Engineering. MIT Press.

Keutsch Group. (2025). SCoPEx. https://www.keutschgroup.com/scopex

Kimmelman, J., & London, A. J. (2015). The Structure of Clinical Translation: Efficiency, Information, and Ethics. *Hastings Center Report*, *45*(2), 27–39. https://doi.org/10.1002/hast.433

Kravitz, B., Robock, A., Boucher, O., et al. (2011). The Geoengineering Model Intercomparison Project (GeoMIP). Atmospheric Science Letters, 12(2), 162–167. https://doi.org/10.1002/asl.316

Kravitz, B., Robock, A., Tilmes, S., et al. (2015). The Geoengineering Model Intercomparison Project Phase 6 (GeoMIP6): simulation design and preliminary results. Geoscientific Model Development, 8, 3379–3392. https://doi.org/10.5194/gmd-8-3379-2015

Kumar J., A., & Chakrabarti, A. (2012). Bounded awareness and tacit knowledge: Revisiting Challenger disaster. Journal of Knowledge Management, 16(6), 934–949. https://doi.org/10.1108/13673271211276209

Kuswanto, H., Kravitz, B., Miftahurrohmah, B., Fauzi, F., Sopahaluwaken, A., & Moore, J. (2022). Impact of solar geoengineering on temperatures over the Indonesian Maritime Continent. International Journal of Climatology, 42(5), 2795–2814. https://doi.org/10.1002/joc.7391

Lacarte, V., Amaral, J., Chaves-González, D., Sáiz, A. M., & Harris, J. (2023). Migration, integration, and diaspora engagement in the Caribbean: A policy review (Discussion Paper). Inter-American Development Bank & Migration Policy Institute. https://doi.org/10.18235/0004769

Lam, V. (2022). Abrupt climate changes and tipping points: Epistemic and methodological issues. In G. Pellegrino & M. Di Paola (Eds.), Handbook of the philosophy of climate change. Springer.

Le Pargneux, A., Chater, N., & Zeitoun, H. (2024). Contractualist tendencies and reasoning in moral judgment and decision making. Cognition, 249, 105838.

Lee, W. R., McMartin, D., Visioni, D., & Adler, S. (2021). Sunlight reflection management primer. https://dfr.oregon.gov/pages/index.aspx

Levine, R. J. (1979). Clarifying the concepts of research ethics. Hastings Center Report, 9(3), 21–26. https://doi.org/10.2307/3560793

Levine, S., Chater, N., Tenenbaum, J. B., & Cushman, F. (2024). Resource-rational contractualism: A triple theory of moral cognition. Behavioral and Brain Sciences, 1–38.

Lie-Panis, J., & André, J.-B. (2022). Cooperation as a signal of time preferences. Proceedings of the Royal Society B: Biological Sciences, 289(1973). https://doi.org/10.1098/rspb.2021.2266

Lipworth, W., Stewart, C., & Kerridge, I. (2018). The Need for Beneficence and Prudence in Clinical Innovation with Autologous Stem Cells. Perspectives in Biology and Medicine, 61(1), 90–105. https://doi.org/10.1353/pbm.2018.0029

London, A. (2022). For the Common Good: Philosophical Foundations of Research Ethics. Oxford University Press. https://www.cmu.edu/dietrich/philosophy/docs/london/london-for-the-common-good.pdf

Low, S., Fritz, L., Baum, C. M., & Sovacool, B. K. (2024). Public perceptions on solar geoengineering from focus groups in 22 countries. Communications Earth & Environment, 5(1), 352. https://doi.org/10.1038/s43247-024-01518-0

Luna, F. (2014). 'Vulnerability', an interesting concept for public health: The case of older persons. Public Health Ethics, 7(2), 180–194. https://doi.org/10.1093/phe/phu012

Luna, F. (2019). Identifying and evaluating layers of vulnerability - a way forward. Developing World Bioethics, 19(2), 86–95. https://doi.org/10.1111/dewb.12206

Luna, F. (forthcoming). The ideal and non- ideal in Bioethics-decision Making in an imperfect World, Springer.

Mackenzie, C. (2019). Feminist innovation in philosophy: relational autonomy and social justice. Women's Studies International Forum, 72, 144–151. https://doi.org/10.1016/j.wsif.2018.05.003

Macnaghten, P., & Guivant, J. S. (2011). Converging citizens? Nanotechnology and the political imaginary of public engagement in Brazil and the United Kingdom. Public Understanding of Science, 20(2), 207–220. https://doi.org/10.1177/0963662510379084

Macnaghten, P., & Guivant, J. S. (2020). Narrative as a resource for inclusive governance: a UK-Brazil comparison of public responses to nanotechnology. Journal of Responsible Innovation, 7, 1–21.

Make Sunsets. (2025). Make Sunsets. https://makesunsets.com/

Marmot, M., & Bell, R. (2012). Fair society, healthy lives. Public Health, 126(Suppl 1), S4–S10.

https://doi.org/10.1016/j.puhe.2012.05.014

Mastroianni, A. M., & Gilbert, D. T. (2023). The illusion of moral decline. Nature, 618(7966), 782–789.

Mastroleo, I. (2025a). A terminological analysis of the neutral concept of geoengineering: an ethical requirement before doing ethics and governance of SRM research v6.0 [Work in progress, available upon request].

Mastroleo, I. (2025b). Ethics and governance of SRM research: a critical introductory review v3.0 [Work in progress, available upon request].

Mastroleo, I., & Holzer, F. (2020). New non-validated practice: An enhanced definition of innovative practice for medicine. Law, Innovation and Technology, 12(2), 318–346. https://doi.org/10.1080/17579961.2020.1815405

Mattoo, A., & Subramanian, A. (2012). Equity in Climate Change: An Analytical Review. World Development, 40(6). https://doi.org/10.1016/j.worlddev.2011.11.007

McGregor, S. (2003). Government transparency: the citizen perspective and experience with food and health products policy. International Journal of Consumer Studies, 27(2), 168–175.

McIntyre, A. (2023). Doctrine of Double Effect. In E. N. Zalta & U. Nodelman (Eds.), The Stanford Encyclopedia of Philosophy (Winter 2023) Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/win2023/entries/double-effect/

McKinnon, C. (2019). Sleepwalking into lock-in? Avoiding wrongs to future people in the governance of solar radiation management research. Environmental Politics, 28(3), 441–459. https://doi.org/10.1080/09644016.2018.1450344

McLaren, D. (2016). Mitigation deterrence and the “moral hazard” of solar radiation management. Earth’s Future, 4(12), 596–602. https://doi.org/10.1002/2016EF000445

McLaren, D. (2021). The politics and governance of research into solar geoengineering. WIREs Climate Change, 12(3), e707. https://doi.org/10.1002/wcc.707

Meadows, J., Mansour, A., Gatto, M. R., Li, A., Howard, A., & Bentley, R. (2024). Mental illness and increased vulnerability to negative health effects from extreme heat events: A systematic review. Psychiatry Research, 332, 115678.

Mercado, G., et al. (2023). Supporting Nature-Based Solutions via Nature-Based Thinking across European and Latin American cities. Ambio, 53(1), 79–94.

Mercer, A. (2014). An Examination of Emerging Public and Expert Judgments of Solar Radiation Management [Tesis doctoral, University of Calgary]. https://prism.ucalgary.ca.

Mercer, A. M., Keith, D. W., & Sharp, J. D. (2011). Public understanding of solar radiation management. Environmental Research Letters, 6(4), 044006. https://doi.org/10.1088/1748-9326/6/4/044006

Merk, C., Pönitzsch, G., Kniebes, C. et al. (2015). Exploring public perceptions of stratospheric sulfate injection. Climatic Change, 130, 299–312. https://doi.org/10.1007/s10584-014-1317-7

Miller, D. (2025). Justice. In E. N. Zalta & U. Nodelman (Eds.), The Stanford Encyclopedia of Philosophy (Spring 2025). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2025/entries/justice/

Moore, J., Choi, Y., & Levine, S. (2024). Intuitions of compromise: Utilitarianism vs. contractualism. http://arxiv.org/abs/2410.05496 [preprint].

Morozov, E. (2013). To Save Everything, Click Here: The Folly of Technological Solutionism. Public Affairs.

Morrow, D. R., Kopp, R. E., & Oppenheimer, M. (2009). Toward ethical principles for climate engineering research (Discussion Paper). Princeton University.

Morton, O. (2016). The Planet Remade: How Geoengineering Could Change the World. Princeton University Press.

Myers, S. S., et al. (2025). Connecting planetary boundaries and planetary health: A resilient and stable Earth system is crucial for human health. The Lancet, 406(10501), 315–319. https://doi.org/10.1016/S0140-6736(25)01256-5

National Academies of Sciences, Engineering, and Medicine (NASEM). (2021). Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance. National Academies Press. https://doi.org/10.17226/25762

National Research Council Committee on Geoengineering Climate. (2015). Climate intervention: Reflecting sunlight to cool earth. National Academies Press.

NOAA Chemical Sciences Laboratory. (n.d.). SABRE: Stratospheric Aerosol processes, Budget and Radiative Effects. https://csl.noaa.gov/projects/sabre/

Nuffield Council on Bioethics. (2025). Climate change and health: embedding ethics into policy and decision making https://cdn.nuffieldbioethics.org/wp-content/uploads/Climate-change-and-health-embedding-ethics-into-policy-and-decision-making-FINAL.pdf

Nussbaum, M. C. (2011). Creating capabilities: The human development approach. Harvard University Press.

Obahoundje, S., Nguessan-Bi, V. H., Diedhiou, A., Kravitz, B., & Moore, J. C. (2023). Implication of stratospheric aerosol geoengineering on compound precipitation and temperature extremes in Africa. Science of the Total Environment, 863, 160806.

Office of Science and Technology Policy (OSTP). (2023). Congressionally Mandated Research Plan and an Initial Research Governance Framework Related to Solar Radiation Modification. https://bidenwhitehouse.archives.gov/wp-content/uploads/2023/06/Congressionally-Mandated-Report-on-Solar-Radiation-Modification.pdf

Oxford Martin School. (n.d.). Oxford Principles for Geoengineering Governance.

https://www.oxfordmartin.ox.ac.uk/geoengineering

Paris Agreement. (2015). Adoption of the Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Parson, E. A., Buck, H. J., Jinnah, S., Moreno-Cruz, J., & Nicholson, S. (2024). Toward an evidence-informed, responsible, and inclusive debate on solar geoengineering: A response to the proposed non-use agreement. WIREs Climate Change, e903. https://doi.org/10.1002/wcc.903

Patel, T. D., Odoulami, R. C., Pinto, I., Egbebiyi, T. S., Lennard, C., Abiodun, B. J., & New, M. (2023). Potential impact of stratospheric aerosol geoengineering on projected temperature and precipitation extremes in South Africa. Environmental Research: Climate, 2(2), 025003. https://doi.org/10.1088/2752-5295/acdaec

Patel, V. (2023). The right to mental health. The Lancet, 402(10411), 1412–1413. https://doi.org/10.1016/S0140-6736(23)02241-9

Pellizzoni, L. (2003). Uncertainty and participatory democracy. Environmental Values, 12(2), 195–224. https://doi.org/10.3197/096327103129341298

Perlaviciute, G. (2022). Contested climate policies and the four Ds of public participation: From normative standards to what people want. WIREs Climate Change, 13(1), e749. https://doi.org/10.1002/wcc.749

Poll, I. (2024). Contrail control – what are we waiting for? Royal Aeronautical Society. https://www.aerosociety.com/news/contrail-control-what-are-we-waiting-for/

QC Foundation. (2025). QC Foundation. https://www.qc.foundation/

Quaas, J., et al. (2024). Solar radiation modification: SAPEA evidence review report. SAPEA. https://epubl.ktu.edu/object/elaba:215283208/

Rahman, A. A., Artaxo, P., Asrat, A., & Parker, A. (2018). Developing countries must lead on solar geoengineering research. Nature, 556(7699), 22–24. https://doi.org/10.1038/d41586-018-03917-8

Rayner, S., Heyward, C., Kruger, T., Pidgeon, N., Redgwell, C., & Savulescu, J. (2013). The Oxford Principles. Climatic Change, 121(3), 499–512. https://doi.org/10.1007/s10584-012-0675-2

Rayner, S., Redgwell, C., Savulescu, J., Pidgeon, N., & Kruger, T. (2009). Memorandum on draft principles for the conduct of geoengineering research. House of Commons Science and Technology Committee

Reflective Institute. (2025). Reflective Institute. https://reflective.org/

Reynolds, J. L. (2019). Solar geoengineering to reduce climate change: A review of governance proposals. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *475*(2229), 20190255. https://doi.org/10.1098/rspa.2019.0255

Reynolds, J. L., & Horton, J. B. (2020). An earth system governance perspective on solar geoengineering. Earth System Governance, 3, 100043. https://doi.org/10.1016/j.esg.2020.100043

Reynolds, J. L., Contreras, J. L., & Sarnoff, J. D. (2022). Solar radiation modification: Governance gaps and challenges (C2G Report). Carnegie Climate Governance Initiative.

Reynolds, J., Ghosh, A., Harihar, N., & Prayank, J. (2022). *Solar radiation modification: Governance gaps and challenges* (C2G Policy Brief No. 11). C2G Carnegie Climate Governance Initiative. https://www.c2g2.net/wp-content/uploads/C2G-PB-11-Governance-Gaps-and-Challenges.pdf

Richter, J. H., et al. (2022). Assessing Responses and Impacts of Solar climate intervention on the Earth system with stratospheric aerosol injection (ARISE-SAI): protocol and initial results from the first simulations. Geoscientific Model Development, 15, 8221–8243. https://doi.org/10.5194/gmd-15-8221-2022

Ricke, K. L., Moreno-Cruz, J. B., & Caldeira, K. (2013). Strategic incentives for climate geoengineering coalitions to exclude broad participation. Environmental Research Letters, 8(1), 014021. https://doi.org/10.1088/1748-9326/8/1/014021

Robeyns, I., & Byskov, M. F. (2025). The capability approach. En E. N. Zalta & U. Nodelman (Eds.), The Stanford encyclopedia of philosophy (Summer 2025 ed.). Stanford University. https://plato.stanford.edu/archives/sum2025/entries/capability-approach/

Robock, A. (2008). 20 reasons why geoengineering may be a bad idea. Bulletin of the Atomic Scientists, 64(2), 14–18.

Rockström, J., Donges, J. F., Fetzer, I., Martin, M. A., Wang-Erlandsson, L., & Richardson, K. (2024). Planetary Boundaries guide humanity's future on Earth. Nature Reviews Earth & Environment, 5(11), 773–788. https://doi.org/10.1038/s43017-024-00597-z

Romanello, M., et al. (2025). The 2025 report of the Lancet Countdown on health and climate change. The Lancet, S0140-6736(25)01919-1. https://doi.org/10.1016/S0140-6736(25)01919-1

Rosenthal, S., Irvine, P. J., Cummings, C. L., & Ho, S. S. (2023). Exposure to climate change information predicts public support for solar geoengineering in Singapore and the United States. Scientific Reports, 13(1), 19874. https://doi.org/10.1038/s41598-023-46952-w

Rowe, G., & Frewer, L. J. (2000). Public Participation Methods: A Framework for Evaluation. Science, Technology, & Human Values, 25(1), 3–29. https://doi.org/10.1177/016224390002500101

Rowe, G., & Frewer, L. J. (2004). Evaluating public-participation exercises: A research agenda. Science, Technology, & Human Values, 29(4), 512–556. https://doi.org/10.1177/0162243903259197

Royal Society. (2009). Geoengineering the climate: Science, governance and uncertainty. The Royal Society. https://royalsociety.org/news-resources/publications/2009/geoengineering-climate/

Royal Society. (2025). Solar radiation modification: Policy briefing. The Royal Society.

https://royalsociety.org/news-resources/projects/solar-radiation-modification/

Ruger, J. P. (2004). Health and social justice. The Lancet, 364(9439), 1075–1080. https://doi.org/10.1016/S0140-6736(04)17064-5

Ruger, J. P. (2006). Toward a Theory of a Right to Health: Capability and Incompletely Theorized Agreements. Yale Journal of Law & the Humanities, 18(2), 3.

Saglie, I.-L., Inderberg, T. H., & Rognstad, H. (2020). What shapes municipalities' perceptions of fairness in windpower developments? Local Environment, 25(2), 147–161.

Santi, M. F. (2015). El debate sobre los daños en investigación en ciencias sociales. Revista de Bioética y Derecho, 34, 11–25. https://doi.org/10.1344/rbd2015.34.12063

Schäfer, S., Lawrence, M., Stelzer, H., Born, W., Low, S., Aaheim, A., Adriázola, P., Betz, G., Boucher, O., Carius, A., Devine-Right, P., Gullberg, A. T., Haszeldine, S., Haywood, J., Houghton, K., Ibarrola, R., Irvine, P., Kristjansson, J.-E., Lenton, T., Link, J. S. A. ... Vaughan, N. (Eds.). (2015). The European transdisciplinary assessment of climate engineering (EuTRACE). https://doi.org/10.2312/iass.2015.024

Schoenegger, P., & Mintz-Woo, K. (2024). Moral hazards and solar radiation management: Evidence from a large-scale online experiment. Journal of Environmental Psychology, 95, 102288. https://doi.org/10.1016/j.jenvp.2024.102288

Science Advice for Policy by European Academies (SAPEA). (2024). Solar Radiation Modification: Evidence Review Report. https://www.zora.uzh.ch/id/eprint/275185/1/srmerr.pdf

SCoPEx Advisory Committee. (2024). Final Report of the SCoPEx Advisory Committee. https://salatainstitute.harvard.edu/wp-content/uploads/2025/04/Final-SCoPEx-AC-Report-With-Appendices.pdf

Scott, D. (2015). The Limits of Precision. En Levels of Argument: A Comparative Study of Plato's Republic and Aristotle's Nicomachean Ethics. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199249640.003.0008

Sen, A. (1999). Development as freedom. Alfred A. Knopf.

SG Deliberation. (2025). SG Deliberation. https://www.sgdeliberation.org/

Sheather, J., Littler, K., Singh, J. A., & Wright, K. (2023). Ethics, climate change and health - a landscape review. Wellcome Open Research, 8, 343. https://doi.org/10.12688/wellcomeopenres.19490.1

Shepherd, J. G., & Working Group on Geoengineering the Climate. (2009). Geoengineering the climate: Science, governance and uncertainty. The Royal Society.

Simons Foundation. (2024a). Simons Foundation funds 14 projects investigating the safety and efficacy of Earth-cooling techniques. https://www.simonsfoundation.org/2024/06/12/simons-foundation-funds-14-projects-exploring-earth-cooling-techniques-as-part-of-new-international-research-program/

Simons Foundation. (n.d.). Solar Radiation Management (Program page). https://www.simonsfoundation.org/grant/solar-radiation-management/

Singer, P. (2016). One World Now: The Ethics of Globalization. Yale University Press.

Smith, W. (2020). The cost of stratospheric aerosol injection through 2100. Environmental Research Letters, 15(11), 114024. https://doi.org/10.1088/1748-9326/aba7e7

Soden, B. J., Wetherald, R. T., Stenchikov, G. L., & Robock, A. (2002). Global cooling after the eruption of Mount Pinatubo: A test of climate feedback by water vapor. Science, 296(5568), 727–730. https://doi.org/10.1126/science.296.5568.727

Solar Geo. (2025). SolarGeo.Org. https://www.solargeo.org

Solar Radiation Management Governance Initiative. (2011). Solar radiation management: The governance of research. The Royal Society. https://royalsociety.org/topics-policy/projects/solar-radiation-management-governance-initiative/

Soldatenko, S. A. (2017). Weather and Climate Manipulation as an Optimal Control for Adaptive Dynamical Systems. Complexity, 2017(1), 4615072. https://doi.org/10.1155/2017/4615072

Southern Cross University. (2023). Cloud brightening reduces coral bleaching: new study. https://www.scu.edu.au/engage/newsroom/2023/cloud-brightening-reduces-coral-bleaching-new-study.php

SPICE Project. (2012). SPICE: Stratospheric Particle Injection for Climate Engineering (project archive). University of Bristol. http://www.bristol.ac.uk/engineering/research/spice/

SRM Primer. (2024). SRM Primer Climate Engineering Cornell University. Retrieved June 3, 2024, from https://www.srmprimer.org/the-primer; https://web.archive.org/web/20231021221253/https://www.srmprimer.org/the-primer

SRM360. (2025). Emissions cuts, carbon removal, and SRM. https://srm360.org/infographic/emissions-cuts-carbon-removal-and-srm/

SRM360. (2025). SRM360. https://srm360.org/

Stardust Solutions. (2025). Stardust Solutions. https://www.stardustsolutions.com/

Stilgoe, J. (2015). Experiment Earth: Responsible innovation in geoengineering. Earthscan.

Stirling, A., & Grove-White, R. (1999). The politics of GM food: Risk, science and public trust (Special Briefing No. 5). University of Sussex.

Sugiyama, M., Takanobu Kosugi, Ishii, A., & Asayama, S. (2016). Public attitudes to climate engineering research and field experiments: Preliminary results of a web survey on students' perception in six Asia-Pacific countries. [Unpublished]. https://doi.org/10.13140/RG.2.2.17837.28640

Sukhera, J. (2022). Narrative Reviews: Flexible, Rigorous, and Practical. Journal of Graduate Medical

Education, 14(4), 414–417. doi:10.4300/JGME-D-22-00480.1

Surprise, K., McLaren, D., Möller, I., Sapinski, J. P., Stabinsky, D., & Stephens, J. C. (2025). Profit-seeking solar geoengineering exemplifies broader risks of market-based climate governance. Earth System Governance, 23, 100242. https://doi.org/10.1016/j.esg.2025.100242

Svoboda, T., & Irvine, P. (2014). Ethical and technical challenges in compensating for harm due to solar radiation management geoengineering. Ethics, Policy & Environment, 17(2), 157–174. https://doi.org/10.1080/21550085.2014.927962

Symes, M. (2023). Future-Proofing Our Climate and Weather: Opportunity Space v1.0. Advanced Research and Invention Agency (ARIA). https://www.aria.org.uk/media/hzafl3mg/aria-future-proofing-our-climate-and-weather.pd f

Symes, M. (2024a). Exploring Options for Actively Cooling the Earth: Programme Thesis v2.0. Advanced Research and Invention Agency (ARIA). https://www.aria.org.uk/media/wotbzgsm/aria-actively-cooling-the-earth-programme.pdf

Symes, M. (2024b). Future-Proofing Our Climate and Weather: Opportunity Space v2.0. Advanced Research and Invention Agency (ARIA). https://www.aria.org.uk/media/hzafl3mg/aria-future-proofing-our-climate-and-weather.pdf

Taebi, B., et al. (2023). Climate Engineering and the Future of Justice. In I. van de Poel et al. (Eds.), Ethics of Socially Disruptive Technologies: An Introduction (pp. 83–112). Open Book Publishers. https://doi.org/10.11647/obp.0366.04

Tanaka, S., & Matsubayashi, T. (2025). The light of life: The effects of sunlight on suicide. Journal of Health Economics, 99, 102947. https://doi.org/10.1016/j.jhealeco.2024.102947

Temple, J. (2025). Inside a new quest to save the “doomsday glacier.” MIT Technology Review. https://www.technologyreview.com/2025/03/21/1113396/inside-a-new-quest-to-save-the-doomsday-glacier/

The Alliance for Just Deliberation on Solar Geoengineering (DSG). (2025). Advancing Justice in Solar Geoengineering Deliberation. https://www.sgdeliberation.org/

The Degrees Foundation. (n.d.). Degrees Socio-Political Fund. https://www.degreesfoundation.ngo/

The Degrees Initiative. (n.d.). Modeling Grants Program. https://www.degrees.ngo/grants

Tilmes, S., et al. (2018). CESM1 (WACCM) stratospheric aerosol geoengineering large ensemble project. Bulletin of the American Meteorological Society, 99(11), 2361–2371. https://doi.org/10.1175/BAMS-D-17-0267.1

Tracy, S. M., Moch, J. M., Eastham, S. D., & Buonocore, J. J. (2022). Stratospheric aerosol injection may impact global systems and human health outcomes. Elementa: Science of the Anthropocene, 10(1), 00047. https://doi.org/10.1525/elementa.2022.00047

Turner, M. (2025). Five Insights We've Gained From Communicating on SRM. SRM360. https://srm360.org/perspective/insights-from-communicating-on-srm/

Tyler, T. R. (1996). The relationship of the outcome and procedural fairness: How does knowing the outcome influence judgments about the procedure? Social Justice Research, 9(4), 311–325.

Tyler, T. R. (2000). Social justice: Outcome and procedure. International Journal of Psychology, 35(2), 117–125.

U.S. Department of Homeland Security. (2010). DHS risk lexicon – 2010 edition. Office of Risk Management and Analysis. , National Protection and Programs Directorate. https://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf

United Nations Educational, Scientific and Cultural Organization (UNESCO), World Commission on the Ethics of Scientific Knowledge and Technology (COMEST). (2021). Concept note of COMEST on the ethics of climate engineering. UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000379991

United Nations Environment Programme (UNEP) & International Science Council (ISC). (2024). Navigating New Horizons: A global foresight report on planetary health and human wellbeing. https://council.science/wp-content/uploads/2024/07/Global-Foresight-Report-2024-FINAL.pdf

United Nations Environment Programme (UNEP). (2023/2024). UNEA-6 Major Groups and Stakeholders: Regional statements (UNEP/EA.6/INF/3). https://documents.un.org/access.nsf/get?DS=UNEP/EA.6/INF/3&Lang=E&OpenAgent

United Nations Environment Programme (UNEP). (2023a). Kigali Amendment to the Montreal Protocol: Fact sheet. https://ozone.unep.org/resources/factsheet/kigali-amendment

United Nations Environment Programme (UNEP). (2023b). One Atmosphere: An independent expert review on Solar Radiation Modification research and deployment. https://wedocs.unep.org/bitstream/handle/20.500.11822/41903/one_atmosphere.pdf

United Nations Environment Programme (UNEP). (2024b). Sixth session of the United Nations Environment Assembly (UNEA-6) – session portal. https://www.unep.org/environmentassembly/unea6

United Nations Environment Programme (UNEP). (2024b). Solar Radiation Modification (draft resolution materials for UNEA-6). https://resolutions.unep.org/resolutions/uploads/a_5_-_solar_radiation_modification.pdf

United Nations Environment Programme (UNEP). (2024c). UNEA-6 Major Groups and Stakeholders: Regional statements (UNEP/EA.6/INF/3). https://documents.un.org/access.nsf/get?DS=UNEP/EA.6/INF/3&Lang=E&OpenAgent

United Nations Environment Programme (UNEP). (2025a). Consultative workshop and science-policy dialogue on solar radiation modification. https://www.unep.org/events/workshop/consultative-workshop-and-science-policy-dialogue-solar-radiation-modification

United Nations Environment Programme (UNEP). (2025b). Multistakeholder Workshop on Solar Radiation Modification. https://www.unep.org/events/workshop/multistakeholder-workshop-solar-radiation-modification

United Nations Environment Programme. (2025). African Ministerial Conference on the Environment (AMCEN). https://www.unep.org/regions/africa/african-ministerial-conference-environment

United Nations Human Rights Council (HRC) Advisory Committee. (2023). Impact of new technologies intended for climate protection on the enjoyment of human rights (A/HRC/54/47). https://digitallibrary.un.org/record/4020175

University of Washington, MCB. (n.d.). Marine Cloud Brightening Program. https://mcb.uw.edu/

Valles, S. A. (2018). Philosophy of population health: philosophy for a new public health era. Routledge.

van der Poel, I. (2022). Socially Disruptive Technologies, Contextual Integrity, and Conservatism About Moral Change. Philosophy & Technology, 35, 82. https://doi.org/10.1007/s13347-022-00578-4

van Vuuren, D. P., Doelman, J. C., Schmidt Tagomori, I., Beusen, A. H. W., Cornell, S. E., Röckstrom, J., Schipper, A. M., Stehfest, E., Ambrosio, G., van den Berg, M., Bouwman, L., Daioglou, V., Harmsen, M., Lucas, P., van der Wijst, K.-I., & van Zeist, W.-J. (2025). Exploring pathways for world development within planetary boundaries. *Nature*, 641(8064), 910–916. https://doi.org/10.1038/s41586-025-08928-w

Varkey, B. (2021). Principles of clinical ethics and their application to practice. *Medical Principles and Practice*, *30*(1), 17–28. https://doi.org/10.1159/000509119

Venkatapuram, S. (2011). Health justice: An argument from the capabilities approach. Polity Press.

Vergunst, F., & Berry, H. L. (2022). Climate Change and Children's Mental Health: A Developmental Perspective. Clinical Psychological Science, 10(4), 767–785. https://doi.org/10.1177/21677026211040787

Vergunst, F., Williamson, R., Massazza, A., Berry, H. L., & Olff, M. (2024). A dual-continuum framework to evaluate climate change impacts on mental health. Nature Mental Health, 2, 1318–1326. https://doi.org/10.1038/s44220-024-00326-x

Wan Mahiyuddin, W. R., et al. (2023). Cardiovascular and respiratory health effects of fine particulate matters (PM2.5): A review on time series studies. Atmosphere, 14(5), 856.

Wang, C., Visioni, D., Chua, G., & Bednarz, E. M. (2025). Air quality impacts of stratospheric aerosol injections are small and mainly driven by changes in climate, not deposition. EGUsphere, 1–29.

Wang, J., Moore, J. C., & Zhao, L. (2023). Changes in apparent temperature and $PM_{2.5}$ around the

Beijing–Tianjin megalopolis under greenhouse gas and stratospheric aerosol intervention scenarios. Earth System Dynamics, 14, 989–1013. https://doi.org/10.5194/esd-14-989-2023

Wang, J., Zhao, L., & Moore, J. C. (2024). Projected thermally driven elderly mortality for Beijing under greenhouse gas and stratospheric aerosol geoengineering scenarios. Earth's Future, 12(7). https://doi.org/10.1029/2024ef004422

Watts, J., & Xipai, W. (2025, October 28). 'Change course now': Humanity has missed 1.5C climate target, says UN head. *The Guardian*. https://www.theguardian.com/environment/2025/oct/28/change-course-now-humanity-has-missed-15c-climate-target-says-un-head

Werndl, C. (2016). On defining climate and climate change. British Journal for the Philosophy of Science, 67(2), 337–364.

White, J. P., Bhui, R., Cushman, F., Tenenbaum, J., & Levine, S. (2024). Moral flexibility in applying queuing norms can be explained by contractualist principles and game-theoretic considerations. Proceedings of the Annual Meeting of the Cognitive Science Society, 46. https://escholarship.org/uc/item/2rg5p0ng

Whyte, K. (2012). Indigenous Peoples, Solar Radiation Management, and Consent. En C. J. Preston (Ed.), Engineering the Climate: The Ethics of Solar Radiation Management. Lexington Books.

Wiener, J. B. (2024). Multi-risk governance of solar radiation modification. European Journal of Risk Regulation, 15(3), 1–20. https://www.cambridge.org/core/journals/european-journal-of-risk-regulation/article/multirisk-governance-of-solar-radiation-modification/E869559BAB6E1EAB5D2B6A083B40E7ED

Williams, B., et al. (2024). AGU Ethical framework principles for climate intervention research. American Geophysical Unio https://research.ulapland.fi/files/40667192/Ethical_Framework_Report.pdf

Wong, P.-H., Douglas, T., & Savulescu, J. (2014). Compensation for geoengineering harms and no-fault climate change compensation (Climate Geoengineering Governance Working Paper 8).

Woodward, J., & Ross, L. (2021). Scientific Explanation. En E. N. Zalta (Ed.), The Stanford Encyclopedia of Philosophy. https://plato.stanford.edu/entries/scientific-explanation/

World Federation of Public Health Associations (2024). Global Charter for the Public's Health (2024 revision). https://www.wfpha.org/the-global-charter-for-the-publics-health/

World Health Organization (WHO) (2008). Climate change and health: Report by the Secretariat (A61/14). https://cdn.who.int/media/docs/default-source/climate-change/report-by-the-secretariat-on-climate-changeand-health.pdf

World Health Organization (WHO) (2020). WHO global strategy on health, environment and climate change: The transformation needed to improve lives and well-being sustainably through healthy environments. World Health Organization.

https://iris.who.int/handle/10665/331959

World Health Organization (WHO) (2021a). Ethics and governance of artificial intelligence for health: WHO guidance. World Health Organization. https://www.who.int/publications/i/item/9789240029200

World Health Organization (WHO) (2021b). Climate change and health vulnerability and adaptation assessment. https://www.who.int/publications/i/item/9789240036383

World Health Organization (WHO) (2021c). COP26 special report on climate change and health: The health argument for climate action. World Health Organization. https://iris.who.int/handle/10665/346168

World Health Organization (WHO) (2022a). Global guidance framework for the responsible use of the life sciences: Mitigating biorisks and governing dual-use research. World Health Organization. https://www.who.int/publications/i/item/9789240056107

World Health Organization (WHO) (2022b). World Health Organization strategy (2022–2026) for the National Action Plan for Health Security. https://www.who.int/publications/i/item/9789240061545

World Health Organization (WHO) (2022c). *World Health Organization strategy (2022–2026) for the National Action Plan for Health Security*. World Health Organization. https://www.who.int/publications/i/item/9789240061545

World Health Organization (WHO) (2022d). Emergency use of unproven clinical interventions outside clinical trials: Ethical considerations. https://apps.who.int/iris/handle/10665/352902

World Health Organization (WHO) (2023). A framework for the quantification and economic valuation of health outcomes originating from health and non-health climate change mitigation and adaptation action. World Health Organization. https://www.who.int/publications/i/item/9789240057906

World Health Organization (WHO) (2024). Climate change and health (WHA77.14) [Resolution]. https://apps.who.int/gb/ebwha/pdf_files/WHA77/A77_R14-en.pdf

World Health Organization (WHO) (2025a). WHO guidance on the ethics of health research priority setting. World Health Organization. https://www.who.int/publications/i/item/9789240110953

World Health Organization (WHO) (2025b). Social listening in infodemic management for public health emergencies: Guidance on ethical considerations. World Health Organization. https://iris.who.int/handle/10665/381013

World Meteorological Organization (WMO). (2025). Global Annual to Decadal Climate Update 2025–2029. https://hadleyserver.metoffice.gov.uk/wmolc/WMO_GADCU_2025-2029.pdf

Xia, L., Nowack, P. J., Tilmes, S., & Robock, A. (2017). Impacts of stratospheric sulfate geoengineering on tropospheric ozone. Atmospheric Chemistry and Physics, 17(19), 11913–11928. https://doi.org/10.5194/acp-17-11913-2017

Yuan, T., Song, H., Oreopoulos, L., Wood, R., Bian, H., Breen, K., Chin, M., Yu, H., Barahona, D., Meyer, K., & Platnick, S. (2024). Abrupt reduction in shipping emission as an inadvertent geoengineering termination shock produces substantial radiative warming. *Communications Earth & Environment*, *5*(1), 281. https://doi.org/10.1038/s43247-024-01442-3

Zingales, L., Sapienza, P., & Guiso, L. (2004). Cultural biases in economic exchange? SSRN Electronic Journal. https://doi.org/10.2139/ssrn.634210

Part VI. Authors' biographies, statements and acknowledgments

Authors' biographies

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Statement on the use of artificial intelligence (AI) tools

Florencia Luna: declares no use of LLMs for generative writing.

María Florencia Santi: declares no use of LLMs and declares the supervised use of https://www.deepl.com/es/translator, and Chat GPT mostly for style correction and translation.

Marco Agustoni: declares the use of Chat GPT for translation.

Inés Camilloni: declares no use of LLMs for generative writing.

María Inés Carabajal: declares no use of LLMs for generative writing and declares the use of https://www.deepl.com/es/translator for translation and style correction.

Timothy Daly: declares no use of AI.

Francisco Garcia-Gibson: declares no use of LLMs.

Gian Franco Lisanti: declares the use of Chat GPT for translation and style correction.

Ignacio Mastroleo: declares no use of LLMs for generative writing, only for searching references (Chat GPT, Gemini).

Paola Buedo: declares no use of AI.

Julieta Nasi: declares the use of https://www.deepl.com/es/translator, https://www.deepl.com/es/write for translation and style correction.

Hassaan Sipra: declares the use of Google NotebookLM for conducting analysis on over 150 WHO publications, including reports, guidances, frameworks, protocols and other technical documents. However, no generative writing was used.

Suchi Talati: declares no use of LLMs for generative writing.

Julia S. Guivant: declares the use of https://www.deepl.com/es/translator for translation and style correction.

Cecilia Hidalgo: declares no use of LLMs for generative writing.

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ARIA: Ignacio Mastroleo (PI), Timothy Daly (co-PI), María Inés Carabajal (Chief Research Officer, Work Package Leader), María Florencia Santi (Work Package Leader), Florencia Luna (Senior researcher), Inés Camilloni (Senior researcher), Julia Guivant (Senior Advisor), Gian Franco Lisanti (Junior Researcher) and Julieta Nasi (Junior researcher).

Further, Hassaan Sipra is a team member on two Degrees Initiative funded projects and one ARIA funded project based out of COMSATS University Islamabad, Pakistan, titled “The impact of climate change and SRM on malaria in South Asia” (Degrees Modeling Fund); “Socio-political dimensions of climate change and SRM in the Pakistani health sector” (Degrees Sociopolitical Fund); and “Evidence-based assessments to guide perceptions, governance, and ethical frameworks for South Asia: Comparing marine cloud brightening strategies vis-à-vis carbon dioxide removal and mitigation efforts” (ARIA).

Finally, Shuchi Talati is a member of the oversight committee for the Exploring Climate Cooling programme, directed and funded by ARIA, and a member of the Advisory Board of Co-CREATE.

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