Internal Report.
Geoengineering: an analytical review of reasons. *

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1 Preliminaries

This internal report aims to develop an analytical review of reasons found in the literature on geoengineering. As the Royal Society [99, p. ix] defines it, *geoengineering* (also called *Earth's system engineering*, *climate engineering*, etc.) is "the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change". This is mainly divided into two general categories: *Solar Radiation Modification*[1] (SRM) and *Carbon Dioxide Removal* (CDR). "SRM" is an umbrella term that refers to interventions such as *Stratospheric Aerosol Injection* (SAI), *Marine Cloud Brightening* (MCB), *Cirrus Cloud Thining* (CCT), and *Space Mirrors* (SM). These techniques seek to increase the reflection of incoming sunlight back to space in order to counter greenhouse gas concentrations, even though they differ in levels of scientific development, costs, risks, and the assessment of potential benefits. SAI is one of the most studied SRM technologies. It involves introducing aerosols (or gases that lead to aerosol formation) into the stratosphere – which begins at different altitudes depending on the region of the planet (high latitudes or tropics) – , to reflect a portion of incoming sunlight back into space.[2]

In this internal report, we provide an overview of arguments against geoengineering (section 3) to better assess the situation and risks, and an overview of arguments in favor of it (section 4) to better understand the debate as a whole. In the Conclusions (section 5), we present our closing remarks and a graphical mapping of the arguments. Ultimately, we also present two argument reconstruction in Appendix A (6).

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[1]Sometimes called *Solar Radiation Management*.

[2]The term "SAI" generally refers to a range of activities, including research, potential deployment, and related practices such as monitoring. Research activities aim to reduce uncertainties, while deployment would involve its use to mitigate the negative impacts of anthropogenic climate change. In this context, the terms "SAI strategy" or "SAI scenario" are used interchangeably to describe the key practical features of a specific SAI intervention that shape its overall balance of risks and benefits. These features include what is injected (e.g., type of aerosol), how and where it is injected (e.g., symmetry, latitude), who carries it out (e.g., unilateral or multilateral actors), and under what conditions (e.g., emergency or non-emergency contexts). Polar injection of SAI, which involves cooling the Arctic and/or the Antarctic, may be the first climate intervention of SRM to be deployed to cool the Earth. But other SRM climate interventions may follow. That's why it is useful to have in mind a definition of SRM that includes single interventions and cocktail interventions (combinations of single interventions)—also referred to as "intervention ensembles" by Kimmelman [66] and Kimmelman & London [67]—as for the future.

2 Methodology

The present work offers an analytical review of reasons found in the literature regarding the research and deployment of geoengineering, intended primarily for researchers in the field and policymakers.[3] The guiding question is factual, rather than directly normative: *which reasons have been given in the literature for and against the research and deployment of geoengineering, and how have they been used?*. The unit of analysis is the argument; more concretely, the reasons in support of or against geoengineering research or deployment. Accordingly, we take no position on the soundness of the arguments reviewed: our aim is descriptive, conceptual, and organizational.

We relied on a pluralist source identification strategy combining academic search engines, cross-referencing of bibliographies, and systematic consultation of institutional reports produced by major scientific and policy advisory bodies (Royal Society, COMEST, IPCC, NASEM, SAPEA, among others). We treat these different types of sources—institutional reports, academic papers, and book chapters—on an equal footing, without assigning differential authority based on source type, since our aim is to map arguments rather than to assess their epistemic weight. Journalistic sources (newspaper articles, opinion columns, and similar media), however, were excluded, as these typically repackage arguments found in academic and institutional publications and raise distinct issues of framing and simplification.

We developed an explicit categorization scheme with broad and narrow argument types, and we articulate the connections between them. The selection and classification of arguments were collectively discussed by the team over the course of the project, through successive meetings spanning several months. Previous reviews of arguments appear, for instance, dispersed across chapters in Quaas et al. [93]. By contrast, we aim to provide a unified classification that enables comparability, ensures broad coverage of the space of reasons, and makes their structure navigable for analysis and evaluation. We describe the methodology and justify the label *analytical review of reasons* in detail in Appendix 7, where we also compare our approach to systematic reviews of reasons [113, 114] and narrative reviews [115].

The arguments we consider are presented in specific entries and cover a wide range of topics, from ethics and politics to tropospheric and stratospheric environmental consequences. Each entry includes the following fields:

- *Other name(s):* Alternative labels under which the argument circulates.
- *Typical target(s):* Whether the argument targets research, deployment, or both.
- *Scope:* The level of geoengineering the argument addresses, following the hierarchical structure represented in Figure 1.
- *Attacks:* Arguments in tension with the one under consideration.
- *Description:* A synthesis of the main idea.
- *References:* Bibliographical locations where the argument appears or is mentioned.

The *Scope* field reflects the hierarchical structure of geoengineering (Figure 1): an argument whose scope is geoengineering in general applies to every node in the tree; one whose scope is SRM applies to that branch and all interventions under it; and one targeting a specific technology, such as SAI applies only to that node.

Additionally, we assign each argument to one or more of the following families, which function as a meta-categorization indicating which facet of the target the argument addresses:

Sociopolitical (SP): This label pertains to the uses we (might) give to geoengineering, the ethics involved, current political and economic debates, and diversified anthropological elements.

Epistemological (EP): This label concerns the methods in which we acquire the knowledge related to geoengineering. It is mostly related to the characteristics of the experimental process.

[3] We acknowledge that this review cannot be the only input for policymakers on geoengineering research or deployment. It does not distill the strongest reasons or provide guidance on how to weigh them. That evaluative work remains necessary and falls outside the scope of the present review.

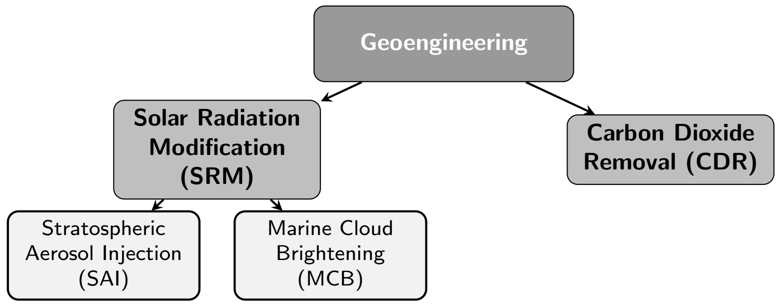

Figure 1: The geoengineering landscape according to the definition by the Royal Society [99]. Their most recent policy briefing [109] focuses mainly on SRM.

Environmental (EN): This label encompasses the arguments that deal with environmental and mostly natural effects and considerations.

These categories are not mutually exclusive: some arguments are primarily associated with one family but would also fit reasonably well with another. We flag such cases in the corresponding entries. The classification of arguments by family, together with the network of attack relations between them, is illustrated graphically in the conclusions (Figures 2, 3, and 4).

3 Arguments against

In the following section, we will present the arguments considered in the literature against geoengineering. We noticed that many of them interact with each other or even trigger one another (take, for example, 3.2 and 3.9). We make it explicit when that is the case.

3.1 Moral hazard (SP)

Other name(s): **Mitigation deterrence/obstruction**; **Trade-offs problem**; **Status quo keeper**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. This is perhaps the most well-known and widely discussed argument against geoengineering. In a few words, the worry is that geoengineering might divert efforts away from emission mitigation, thus prompting slower mitigation than morally required. The COMEST report highlights the great relevance of this argument noting that the social acceptability of funding geoengineering research may depend crucially on how moral hazard concerns are addressed [127, p.16]. Furthermore, the COMEST and the SAPEA reports [102] also discuss this argument from a distinctively economic and political perspective, remarking that geoengineering (more specifically, SRM) may serve as an "alibi" for companies to maintain environmentally harmful production models, while claiming to invest in alternatives to combat climate warming.

> The root problem is simple: Would mere knowledge of a geoengineering method that was demonstrably low in cost and risk weaken the political will to mitigate anthropogenic climate forcing? Knowledge of geoengineering has been characterized as an insurance strategy; in analogy with the moral hazard posed by collective insurance schemes, which encourage behavior that is individually advantageous but not socially optimal, we may ascribe an analogous hazard to geoengineering if it encourages suboptimal investment in mitigation. (Keith [61, p. 276].)

References: Keith [61, p. 275], Robock [96, p. 18], NASEM [29], Hale [39], Lin [72], Jamieson [57], IPCC [52, 53], McLaren [77], Wagner & Merc [123], Smith & Henley [107], COMEST [127], Clark [24, p. 511], Non-Use Agreement [110, p. 9], UNEP [3], SAPEA [102], Carabajal et al. [18, p. 9], Royal Society [109, p. 99], Morrow [82].

3.2 Slippery-slope (SP)

Other name(s): **Lock-in effect of research**.
Typical target(s): Research.
Scope: Geoengineering in general.

Description. The worry is that funding and pursuing research in geoengineering will ultimately lead to deployment, regardless of whether deployment is or not the best course of action. The reason for this stems from the acquired interests of the institutions and people involved.

> Any investment in research and development tends to create a network of professionals and institutions interested in deploying that technology, and the risk of deployment increases as more people and institutions engage in research and development. (Non-Use Agreement [110, p. 6].)

The broader worry can be read in two different ways: as a concern about *premature* deployment, or a concern about *unjustified* deployment. The first might be a problem of timing that could be resolved, whereas the second points to an ethical objection concerning conditions for permissibility.

References: Jamieson [56, p. 336], Bunzl [15, p. 2], Royal Society [99, p. 39], Gardiner [37, p. 289], Betz [9, p. 476], Hulme [49, 50], Jamieson [57], Cairns [16], IPCC [52, 53], Stilgoe [112, pp. 2, 13], Bellamy & Healey [8], Smith & Henley [107], COMEST [127], Clark [24, p. 511], UNEP [3], Non-use Agreement [110], SAPEA [102].

3.3 Playing god (SP)

Other name(s): **Hybris**; **Arrogance**; **Moral overreach**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. The worry is that, by deploying technology that enables humans to control the climate, they will behave and conceive themselves in a dominant or God-like position with respect to nature. This is regarded as bad both from a moral perspective and for the consequences it might have.

> There are certain qualities that humans cannot and should not aspire to, both because they are beyond us and because aspiring to them invites calamity. (Hamilton [40, p. 178].)

> The very idea of intentionally changing climate strikes many people as arrogant, both because it fails to show respect for nature and because it is of a piece with attitudes that have been implicated in causing the problem it purports to solve. (Jamieson [57, p. 534].)

The hybris argument has both secular and religious variants. In the former, the alleged arrogance of humans consists in acting as if we were God; in the latter, it consists in vexing or otherwise failing to respect nature (see, e.g. [42, p. 316] for the distinction; see also Clingerman et al. [25] for more on religious arguments).

References: NASEM [29], Jamieson [56, 57], Hamilton [40, p. 180], Hulme [50, p. 697], Clingerman et al. [25], Katz [58], Weckert [124], Hartman [42], Carr [20], COMEST [127], Clark [24, p. 512], SAPEA [102].

3.4 Inequity increase (SP)

Other name(s): **Climate injustice**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. The general concern is that research and deployment of geoengineering might generate or amplify several forms of injustice in human societies. We list some of them below; mind that they need not be mutually exclusive.

1. **Climate colonialism:** Geoengineering is likely to exacerbate the political and socioeconomic breach between more and less developed countries. Specifically, the threat is that the so-called *global north* will unfairly impose itself over the *global south*, in a power dynamic that replicates that of colonialism.

> In geopolitical discourse, some sources express concern that solar geoengineering could become a form of 'climate colonialism,' where rich countries from the Global North experiment with risky technologies in countries from the Global South. (Carabajal et al. [18, p. 13].)

2. **Bypassing local communities:** Geoengineering might be pursued without meaningful engagement with local communities, and perhaps even against their consent. Thus, there would be a failure in adequately representing the preferences of those who will be affected by the corresponding technologies.

   > [T]he deployment of geoengineering technologies has the potential to violate the human rights of "millions and perhaps billions of people," with a disproportionate impact on Indigenous Peoples, traditional communities, peasants, and fisher folks, among other groups. (CIEL [22, p. 19].)

3. **Climate corporativism:** The research and deployment of geoengineering might fall into the hands of private companies, who will act without adequate regulation and prioritizing their own interests over the public good. A specific problem, closely related to this one, is that of *greenwashing*, where a company leads the general public into falsely thinking that it has environmental commitments.[4]

   > Who would end up controlling geoengineering systems? Governments? Private companies holding patents on proprietary technology? And whose benefit would they have at heart? These systems could pose issues analogous to those raised by pharmaceutical companies and energy conglomerates whose products ostensibly serve the public, but who often value shareholder profits over the public good. (Robock [96, p. 17].)

4. **Free-driver (aka. unilateral deployment) problem**. The concern is that some forms of geoengineering (with SAI as the paradigmatic case) could be so cheap and easy to implement that they might be unilaterally developed by a single agent (nation, company) or a small group of agents.

   > A further governance reservation (...) is that developed nations (or even a single superpower) will deploy geoengineering unilaterally without input from the rest of the world. (Smith & Henley [107, p. 9].)

References: Robock [96], Blackstock [11], NASEM [29], Hulme [50], Clingerman et al. [25], Weitzman [125], McLaren [79], Hourdequin [48], Lawford-Smith [69], COMEST [127], Harding & Moreno-Cruz [80], Clark [24], Non-use Agreement [110], UNEP [3], SAPEA [102], Carabajal et al. [18], McLaren & Corry [78], Cohen et al. [26] Siegert et al. [104, p. 6], Surprise et al. [116], Keith & Visioni [60].

3.5 Effects on warfare (SP)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. The worry is that geoengineering might have exacerbating effects on warfare. This might happen in at least the following ways:

1. **Climate wars** (aka. **threat multiplication**): The lack of consensus on whether, how, where and when to deploy geoengineering might exacerbate the existing tensions between nations, leading to serious conflicts and possibly armed.

   > One worry is that two great powers end up in conflict or at war, for example 'as a result of a dramatic failure, or sequence of failures, in the Indian monsoon' (Morton [83, p. 364]) blamed on solar climate engineering. China's climatic interests might conflict with India's, for example, as they share fates in terms of the monsoon rains. (Corry [27, p. 302])

[4]For a well-known controversy concerning geoengineering and private companies, see the *Make Sunsets* case, studied in Carabajal et al. [18] and Keith & Visioni [60].

2. **Military uses** (aka. **weaponization**): A country or group of countries might deploy geoengineering with the active purpose of damaging another country or group of countries—even though this is prohibited by convention.[5]

> Eighty-five countries, including the United States, have signed the U.N. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), but could techniques developed to control global climate forever be limited to peaceful uses? (Robock [96, p. 17].)

References: Robock [96], Hulme [50], Clingerman et al. [25], Corry [27], COMEST [127], Smith & Henley [107], UNEP [3], SAPEA [102], Carabajal et al. [18].

3.6 Termination shock (SP/EN)

Other name(s): **Earth on life support**; **Termination problem**.
Typical target(s): Deployment.
Scope: SRM.
Attacks: **Risk overstatement** 1.

Description. The worry is that, once the deployment of SRM technologies has started, an abrupt cessation would cause a drastic and rapid increase in global temperatures, known as 'termination shock'. Moreover, ecosystems are sensitive not just to absolute meteorological variables, but also to their rates of change, so they are vulnerable to rapid change induced by termination of SRM. Thus, the use of SRM leaves the Earth completely dependent on continuous human intervention; using a metaphor, it is said that the planet is left 'on life support'.

> Should injections be abruptly halted or significantly reduced in extent, there would be a termination effect where the climate would return to its state without SRM in about a decade or two. If temperatures would have continued to rise significantly without SRM, due to a continuing rise in atmospheric greenhouse gas concentrations, this termination effect would very likely have strong impacts on sensitive planetary systems that cannot adapt quickly, such as natural ecosystems. (Royal Society [109, p. 19].)

References: Robock [96], Brovkin et al. [14], NASEM [29], Clingerman et al. [25], Llanillo et al. [73], Trisos et al. [120], IPCC [52, 53], Parker & Irving [90], Clark [24], UNEP [3], Royal Society [109], Siegert et al. [104, p. 5], Carabajal et al. [18].

3.7 Irreversibility (EN)

Other name(s): **No going back**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Reversibility** 4.5.

Description. The concern is that, if a geoengineering project is implemented and for whatever reasons (say, excessive cooling, negative effects on the biosphere, etc.) it goes awry, it is not clear whether and how its consequences can be reversed.

> We don't know how quickly scientists and engineers could shut down a geoengineering system—or stem its effects—in the event of excessive climate cooling from large volcanic eruptions or other causes. Once we put aerosols into the atmosphere, we cannot remove them. (Robock [96, p. 17].)

References: Robock [96], Keith [61, p. 275], COMEST [127], UNEP [3].

[5] Cf. *Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques* [1].

3.8 Human error (SP)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. The real-world application of SRM depends on technical and political conditions, and these may not proceed as expected. After all, these technologies are developed and deployed by humans. Complex systems are fallible, and humans are prone to making mistakes.

> Complex mechanical systems never work perfectly. Humans can make mistakes in the design, manufacturing, and operation of such systems. (Robock [96, p. 17].)

> [B]enefits of SRM seen in models are not reproducible in real world applications if technical, political, and other conditions do not apply. (McLaren & Corry [78, p. 29].)

References: Robock [96], McLaren & Corry [78].

3.9 Economic costs (SP)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Cost-efficiency** 4.6.

The concern is that geoengineering technologies are infeasible due to the high cost of deploying them at planetary scale. Proponents of geoengineering have claimed that some technologies, most prominently SAI, are relatively affordable — particularly when compared with the costs of emission mitigation. However, these claims have been called into question by critics who argue that current cost estimates are not entirely accurate and/or comprehensive:

> SAI is frequently portrayed as a relatively inexpensive method of climate intervention. (...) However, these calculations assume that the interventions will work as planned, only consider direct costs, and exclude indirect ones such as monitoring and measuring possible impacts, along with the costs of liability related to adverse impacts. Previous studies, (...) indicate that the perception of SAI as a low-cost solution may be a misleading oversimplification of the financial realities. (Siegert et al. [104].)

A related concern about the economics of geoengineering is that funding research in a given technology can close alternative paths of climate action, ultimately leading to the deployment of the technology in question regardless of whether it is the optimal choice (see McKinnon [76, p. 8]). In this sense, economic costs of geoengineering can be seen as triggers of the **Slippery slope** argument (3.2).

References: Robock [96], Smith & Wagner [108], McKinnon [76], Smith [105], COMEST [127], Clark [24], SAPEA [102], Smith et al. [106], Feinberg [35], Bronsther & Xu [13], Siegert et al. [104].

3.10 Effects on regional climates (EN)

Typical target(s): Deployment.
Scope: Mostly SAI.[6]
Attacks: **Risk overstatement** 1.

Description. Implementing SAI may result in reduced precipitation and soil moisture, triggering a regional climate disruption. Of course, this is connected to previous concerns, as it might, in turn, have devastating consequences for the communities involved.[7] Depending on the region and how the mitigation technology is deployed, it may cause agricultural deprivation, food crises, and even water instability.

[6] In the literature, this particular argument is put in terms of a negative effect of SAI's implementation, but it is interesting to note that it could be generalized for many SRM techniques, as Futerman et al. [36] illustrate.

[7] This concern goes hand in hand with the second item on 3.4 in the sense that, ideally, an adequate local engagement will presuppose the discussion over these possibilities and outcomes.

> [I]t is vital to remember that a world cooled by managing sunlight will not be the same as one cooled by lowering emissions. An SRM cooled world would have less precipitation and less evaporation. Some areas would be more protected than others from temperature changes, creating local 'winners' and 'losers'. (Keith et al. [65, p. 426].)

> SAI-induced dimming would reduce the temperature gradient between the equator and the poles, resulting in excess cooling in the tropics, excess warming in the poles, or both compared to existing conditions (...) [E]ven if planetary cooling were achieved, ecosystems would still experience the adverse effects of regional temperature changes, decreasing their long-term resilience.

References: Robock [96], Robock et al. [97], NASEM [29], Moreno-Cruz et al. [81], IPCC [52, 53], Irvine et al. [55], Trisos et al. [120], COMEST [127], Kuswanto et al. [68], Zarnetske et al. [128], UNEP [3], SAPEA [102], CIEL [22], Cohen et al. [26], Siegert et al. [104, p. 6], Futerman et al. [36], Adeliyi et al. [2].

3.11 Harms to the biosphere (EN)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Risk overstatement** 1.

Description. The worry is that deployment of geoengineering technologies might have several negative (and sometimes devastating) effects on the biosphere. The effects in question depend on the particular technology involved. We list some of them, by way of example–keep in mind that the list is not exhaustive:

1. **Ozone depletion.** Associated with (at least) SAI.
   SAI will likely have a negative impact on the ozone layer, specially in polar regions. Without a robust ozone layer, Earth will receive more UV radiation, with the negative consequences this brings for humans and non-human living beings.

2. **Light dimming**. Associated with (at least) SAI, MCB and Marine Microbubbles (MMB).
   The technologies mentioned may reduce photosynthetically active radiation (PAR), which is the kind of light plants can use to make photosynthesis. This would of course negatively affect both land and marine vegetation, with potentially disastrous consequences for ecosystems.

3. **Acidification:** Associated with (at least) SAI and MMB.
   SAI will likely contribute to increase acid depositions in the atmosphere—possibly resulting in acid rains—while also failing to counteract the acidification of the ocean. MMB, in turn, could directly contribute to acidification of the ocean, posing a serious threat to marine biodiversity.

4. **Whitening of the sky.** Associated with SAI.
   The presence of atmospheric aerosols produces a cloudy appearance in the sky, as well as colorful sunsets similar to the effect of volcanic eruptions. This could negatively affect the psychology and behavior of human and non-human animals.

Note that, depending on how the negative effects on the biosphere are distributed and on whether they affect human health, this argument can work as a trigger of 3.10 and 3.12.

References: Robock [96], Doney [32], NASEM [29] Hulme [50], Irvine et al. [55], Trisos et al. [120], Eastham et al. [34], Zarnetske et al. [128], UNEP [3], COMEST [127], CIEL [22], Siegert et al. [104], Henry & Duffey [43], Román de Miguel et al. [98].

3.12 Health risks (EN)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Climate justice** 4.7, **Risk overstatement** 1.

Description. The worry is that deployment of geoengineering might pose threats to human health. These threats might (but need not to) be byproducts of the more general effects on biosphere discussed before (**Harms to biosphere** 3.11).

> SAI may also affect cycling of nitrogen or other nutrients important for aquatic and marine ecosystems, possibly changing the magnitude, intensity, extent, and spatial distribution of algae blooms and hypoxic "dead zones". Nutrient cycling and associated water quality has direct links to public health in terms of aquatic-based food supply, drinking water quality, and access to recreational water bodies. (Tracy et al. [119, p. 9].)

> [S]olar geoengineering could have adverse impacts on health in cases where the burden of infectious diseases does not strictly increase with warming temperatures. If those diseases are a priority for developing countries' climate policy (as malaria still is in much of the world), we suggest that current proposals for geoengineering might therefore be mismatched to the aim of reducing climate injustice and inequality of climate impacts in the health sector. (Carlson et al. [19, p. 6].)

Insofar as humans are part of the biosphere, this argument can be regarded as a trigger for 3.11. Moreover, and depending on which societies are mostly affected by the threats to public health, it may trigger 3.4.

References: Clingerman et al. [25], COMEST [127], Carlson et al. [19], Tracy et al. [119], UNEP [3], CIEL [22], Carabajal et al. [18], Siegert et al [104, p. 6]

3.13 Less sun for solar power (SP)

Typical target(s): Research and deployment.
Scope: SAI.
Attacks: **Risk overstatement** 1.

Description. The worry is that, by reducing solar radiation, SAI would substantively affect our solar power systems.

> Scientists estimate that as little as a 1.8 percent reduction in incoming solar radiation would compensate for a doubling of atmospheric carbon dioxide. Even this small reduction would significantly affect the radiation available for solar power systems—one of the prime alternate methods of generating clean energy—as the response of different solar power systems to total available sunlight is not linear. (Robock [96, p. 16].)

References: Robock [96], Murphy [84], Hulme [50], Ojo et al. [86], Sengupta [103], Kebrich et al. [59], Ballestrín et al. [4].

3.14 Lack of governance (SP)

Typical target(s): Deployment and research.
Scope: Geoengineering in general.

Description. The prevailing apprehension is that, currently, neither nations nor international organizations have the required governance structures to adequately regulate geoengineering technologies. And, as the proponents of the argument uphold, such structures are a necessary condition for legitimate research and/or deployment.

> International concern around the lack or insufficient governance structures for SRM is growing. There is currently no comprehensive governance system, nor a natural forum where this issue can be adequately discussed. As a result, many key questions remain unanswered, such as who will have the authority to deploy SRM technology at a planetary scale and, hence, who will control the planet's metaphorical thermostat, with consequences for the most vulnerable populations. (Carabajal et al. [18, p. 4].)

Beside the above general worry, there are (at least) two more specific concerns about governance.

1. **Organized irresponsibility problem:** If geoengineering were deployed, it would be extremely difficult to assign accountability to specific actors, since environmental risks depend on complex interactions among multiple actors, while responsibility for those risks remain fragmented and diffused.

> [R]esponsibility for the creation and resolution of environmental risks belongs to several institutions and systems (governments, industries, experts and legal system, etc.), but, at the same time, no institution seems to be specifically responsible. This paradoxical circumstance arises because global environmental risks are full of uncertainties and synergistic effects and have complex causal chains and long-term periods of latency. Therefore, assigning responsibility and blame for harmful consequences is extremely difficult, if not impossible. (COMEST [127, p. 17].)

2. **Lack of legitimacy:** The worry is that it might be in principle impossible for global climate intervention to enjoy the required level of political legitimacy.

   > One major reservation about pursuing research into SAI is the challenge of how such a global climate intervention, affecting all humanity and living things, could ever achieve sufficient legitimacy. Beyond achieving a valid distribution of benefits and costs, such an undertaking would also need to be perceived as just in both participatory and procedural terms. (Smith & Henly [107, p. 8-9].)

References: Robock [96], Virgoe [122], Hulme [50], Clingerman et al. [25], IPCC [52, 53], COMEST [127], Smith & Henly [107], UNEP [3], Carabajal et al. [18], Siegert et al. [104, p. 6], SAPEA [102].

3.15 Geopolitical deadlock (SP)

Typical target(s): Research and deployment
Scope: Geoengineering in general.

Description. The concern is that the disagreement between countries regarding geoengineering is so pervasive that settling on a commonly accepted regulatory framework and/or portfolio of climate action may prove impossible.

> The deadlock exists primarily between two groups of states distributed, unevenly, along a continuum (...). The vast majority—around four fifths of those participating or represented in the talks—hold or tend towards a 'skeptical', precautionary stance regarding SRM. They see it as riddled with uncertainty, and fear that ungoverned pursuit of it will delay, disrupt, or undermine the accelerated international action urgently needed to cut greenhouse gas emissions. They want existing fragments of global governance of SRM to be acknowledged and a broader set of knowledges – beyond natural science and that encompass the governance risks and controversies that matter most to them - to be considered. A much smaller but globally influential group of 'permissive' states emphasize keeping SRM options open as a possible way to curtail rising temperatures, thus easing the urgency of decarbonization. (McLaren & Corry [78, p. 28].)

A closely related worry is that, in the context of such a deadlock, countries and organizations will undertake the governance of geoengineering in an uncoordinated manner (see Wiener et al. [126]), perhaps even resulting in multiple different deployment programs coexisting (see Smith & Henley [107, p. 9]).

References: COMEST [127, p. 18], Smith & Henley [107], Non-use Agreement [110], SAPEA [102, pp. 127–131], McLaren & Corry [78], Wiener et al. [126], Surprise et al. [116, p. 3].

3.16 Inconclusive results (EP)

Other name(s): **Insufficient evidence; Speculative techno-fix**
Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Cocktail geoengineering** 2.

Description. The worry is that the available evidence in favor of geoengineering is weak, incomplete, biased, or otherwise spurious. The most extreme manifestations of this worry claim that geoengineering is only a 'speculative techno-fix', without real viability as a climate intervention.

> First, there have been few quantitative studies of the climate impacts of solar geoengineering. Almost all of these studies have focused on stratospheric aerosol injection (...), with only a couple of studies into marine sky brightening (...) and no studies into the climate impacts of other types of solar geoengineering. Critically, many climate impacts sectors are completely absent from the published literature to date, for example: water resources, flood risk, storm damage, terrestrial ecosystems, fisheries, and vector-borne diseases. Of the few sectors that have been studied (i.e., agriculture, ocean ecosystems, and air pollution; see above) there remains considerable work to constrain the potential climate impacts from solar geoengineering. (Irvine et al. [55, p. 98].)

> All claims about potential future risks and benefits of solar geoengineering are speculative, because the technology itself is speculative and no one knows how the future will unfold. (...) This myth [viz. the claim that geoengineering is adequately based on evidence] tries to delegitimize the mainstream view that solar geoengineering is dangerous and falsely claims that the knowledge and perspectives of the small group of scientists advocating for solar geoengineering research is more legitimate than the knowledge of the thousands of diverse people and organizations around the world who are opposed. (Non-use agreement [110, p. 11].)

References: Clingerman et al. [25], IPCC [52, 53], Irvine et al. [55], McLaren [79], COMEST [127], NASEM [29], Non-use agreement [110], SAPEA [102], Committee of Oversight and Government Reform [88], Futerman et al. [36].

3.17 Scalability problem (EP)

Typical target(s): Research.
Scope: Geoengineering in general.

Description. The worry is that the only way of getting reliable knowledge about the benefits, costs and potential risks of geoengineering would be through large-scale deployment. But it should never proceed as a large-scale deployment without that precise reliable knowledge—which seems to undermine the whole geoengineering enterprise.

> On the standard, if idealized model of science, the road to full deployment has a number of way stations each of which offer an opportunity to assess benefit under increasingly realistic conditions. (...) In medicine we can follow this procedure because of something we take for granted—our object of interest is reasonably modular or encapsulated. (...) But what if the object of your interest is not modular or encapsulated? What do you do then? For that, after all, is the feature that big 'G' geoengineering proposals have in common. They call for interventions on systems that lack just this characteristic. You cannot encapsulate part of the atmosphere and it is too complex to be able to build a realistic non-virtual model at scale. As such, it is reasonable to ask whether we could ever have a sound basis for moving to full deployment of any such proposed intervention. And if not, then why bother to even research such proposals in the first place? (Bunzl [15, p. 2].)

> By their very nature, it is impossible to test geoengineering technologies for their intended impact on the climate without large-scale outdoor deployment, which would lock in any harmful and potentially irreversible impacts and turn the Earth into a risky laboratory. Research showing theoretical benefits tends to use highly idealized models underplaying harmful impacts and the likelihood that deployment would not go as planned in the real world. (CIEL [22, p. 7].)

References: Bunzl [15, p. 2], COMEST [127], Biermann et al. [10], Non-use Agreement [110], CIEL [22], SAPEA [102].

3.18 Negationism (SP/EP)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. Climate change negationists reject the idea that human actions are (solely and uniquely) responsible for the increase in the planet's temperature. In this sense, climate change has no anthropogenic causes. For them, the planet naturally changes, and these changes have natural causes. Take, as an example, the *Global Warming Petition Project* [95][8], the statements from the *Friends of Science* organization[9] or the reports presented by the *Nongovernmental International Panel on Climate Change* (NIPCC), which claim the following:

> In contrast to the studies described above, which try but fail to find a consensus in support of the claim that global warming is man-made and dangerous, many authors and surveys have found widespread disagreement or even that a majority of scientists oppose the alleged consensus. These surveys and studies generally suffer the same methodological errors as afflict the ones described above, but they suggest that even playing by the alarmists' rules, the results demonstrate disagreement rather than consensus. (NIPCC [51, p. 20].)

In any case, some argue that geoengineering could interfere with natural processes or that it should be rejected because its development assumes anthropogenic origins to climate change.

References: Nongovernmental International Panel on Climate Change [51], Committee of Oversight and Government Reform [88].

4 Arguments in favor

As we did before, in the following section we will introduce an array of arguments from the geoengineering literature, but in this scenario we present the arguments that are in favor of geoengineering strategies. As before, many of the arguments interact with each other or even trigger one another (take, for example, 4.6, 4.9).

4.1 Safety net (EN)

Other name(s): **Insurance policy**; **Plan B**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. The idea is that geoengineering technologies can be used as a 'safety net', a 'hedge' or an 'insurance policy' to slow down the negative effects of climate change or attenuate their consequences. This idea is most frequently advanced in discussions about tipping points: it is said that geoengineering can help in preventing them from occurring, and in ameliorating their consequences if they do occur.

> The main climate engineering imaginary analyzed in this article (...) posits the desirability of a research program into climate engineering technologies framed as a 'Plan B' – that is, as a fallback option or second-best option rather than as a preferred option or replacement for mitigation (which remains 'Plan A'). Reluctant Geoengineering depicts, via modeling and scenarios, certain technologies as possible means to avoid or deal with the dystopian vision of rapid or dangerous climate change in a future suffering from increasing climatic instability and continually failing or inadequate global efforts to curb emissions of greenhouse gases. It is 'reluctant' in that climate engineering is advanced in a 'worth a try' style of argumentation that tends not to hide uncertainties and (environmental) risks. (Corry [27, p. 299].)

> SRM could alter the global climate within months (...) In contrast, because of the carbon cycle's inertia, even a massive programme of emission cuts or CO2 removal will take many decades to slow global warming discernibly. SRM's speed provides strong grounds to pursue it as a hedge against the real but unlikely possibility that climate is much more sensitive than expected to rising levels of greenhouse gases, or against extreme impacts such as major ice-sheet collapse. (Keith et al. [65, p. 426].)

[8] We are aware of the existence of bibliography that casts doubt over the credentials of the experts associated to such a project (see Caserini et al. [21]), but since our aim here is to present the arguments and not evaluate the information involved, we will leave that aside.

[9] https://friendsofscience.org/.

References: Victor [121], Keith et al. [65] Olson [87, p. 29], Heutel et al. [44], Corry [27], Chen et al. [23], Bellamy [7], Lee et al. [70], Futerman et al. [36], Henry & Duffey [43], Bednarz et al. [6], Goddard et al. [38], Siegert et al. [104], Lenton et al [71, pp. 63 ff.].

4.2 Lesser of two evils (SP)

Other name(s): **Arm the future**; **Last resort option**; **Risk-risk framework**.
Typical target(s): Research now, and potential deployment in the future.
Scope: Geoengineering in general.

Description. This is perhaps the most discussed argument for research in geoengineering. The general idea is that, at some point in the future, deploying geoengineering might turn out to be the best option we have to face the disastrous consequences of climate change. But for this option to be available in at all, we must pursue research in geoengineering in the present. Therefore, we should research geoengineering.

> [R]esearch should continue on whether ICC [i.e. intentional climate change] can be carried out in a way that is consistent with the conditions that I have outlined. My reason for this is straightforward: we may reach a point at which ICC is the lesser of two evils. (Jamieson [56, p. 332-333].)

> [I]f the failure to act aggressively on mitigation continues, then at some point (probably 40 years or more into the future) we may end up facing a choice between allowing catastrophic impacts to occur, or engaging in geoengineering. Both, it is conceded, are bad options. But engaging in geoengineering is less bad than allowing catastrophic climate change. Therefore, the argument continues, if we end up facing the choice, we should choose geoengineering. However, if we do not start doing serious research on geoengineering now, then we will not be in a position to choose that option should the nightmare scenario arise. Therefore, we should start doing that research now. (Gardiner [37, p. 1-2].)

References: Crutzen [30, p. 214], Jamieson [56], Schneider [101, p. 300], Royal Society [99, p. 44]. Gardiner [37], Keith et al. [65], Betz [9], Preston [92], Svoboda [117], Blomfield [12].

4.3 Research first (SP)

Other name(s): **Science-first**; **Duty to research**.
Typical target(s): Research
Scope: Geoengineering in general.

Description. This argument also intends to establish an obligation to research. However, unlike the **Lesser of two evils** argument (4.2), it does not rely on the premise that deployment of geoengineering might be warranted in the future. Instead, it appeals to the more general claims that knowledge is desirable, and that it is better to have more options than fewer.

> The case for research in almost any field seems obvious and unassailable. It is better to know more than less, serious research means peer-reviewed publication and the weeding out of the worst ideas, and research gives us options and capabilities to respond to dire or unexpected situations. (Jamieson [56, p. 333].)

> Cicerone [President of the National Academy of Sciences] believes that we should separate out questions about research on geoengineering from those concerning actual deployment. On the one hand, he supports allowing research and peer-review publication, since this will help us to "weed out bad proposals" and "encourage good proposals", and because knowledge is worthwhile for its own sake. (Gardiner [37, p. 5].)

Some variants of this argument appeal to the additional claim that research in geoengineering is a duty to future generations:

> Seeking to hide knowledge from the future is the wrong response for several reasons. First, it is indefensible from the standpoint of intergenerational justice. Our generation (with generous contributions from immediately preceding generations) will likely bequeath to our descendants a substantially degraded environment and a breathtaking carbon "debt" which they will struggle mightily to repay (...). In such a context, is it justified for us to deprive future generations of tools that may lessen the pain we have inflicted? They may or may not use these tools, but surely those decisions are *theirs* to make. (Smith & Henley [107, p. 8], original emphasis.)

References: Jamieson [56], Gardiner [37], Smith & Henley [107], Non-use agreement [110, p. 4], McLaren & Corry [78].

4.4 Buying time (SP)

Other name(s): **Peak shaving**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.

Description. Many arguments for geoengineering appeal to the possibility of a climate emergency. In contrast, the **Buying time** argument proposes to include geoengineering in the ordinary climate action agenda. It relies on the premise that an abrupt decarbonization is not feasible, since it would produce a massive social, economical and political crisis. Hence, geoengineering can be used as a precautionary, temporary measure used to ameliorate the consequences of climate change while societies make a smoother transition to a carbon-free economy.

> In an interesting shift away from the emergency framing of the Plan B imaginary and towards a more governmental approach, some leading climate engineering researchers have recently argued in favor of a 'temporary, moderate and responsive scenario for solar geoengineering' (Keith and MacMartin [64, p. 201]). In this scenario, SRM would be started not as an emergency measure but rather as a precaution while the jury remains out on the ultimate success or failure of mitigation and adaptation. Stratospheric aerosols would be introduced early but gradually to offset only up to half of anthropogenic climate forcing and only for as long as 'acceptable'. (...) In this version, SRM is a provider of a 'breathing space'. (Corry [27, p. 308].)

> [I]f a society takes a lot of time to solve a specific problem, it might be prudent to buy time by technological means. Even if the problem might be solved within less time in principle (as, in our case, by aggressive immediate abatement of GHG-emissions), buying time might be reasonable if the trade-offs of radical solutions look nasty and repugnant. (Neuber & Ott [85, p. 1].)

References: Crutzen [30], Olson [87], Keith & MacMartin [64], Schäffer et al. [100, p. 243], Horton [47], Corry [27], MacMartin et al. [74], Heutel et al. [45], Neuber & Ott [85], Parson & Keith [91].

4.5 Reversibility (EN)

Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Irreversibility** 3.7.

Description. The claim is that, for many geoengineering technologies, the interventions are reversible: effects dissipate once interventions are stopped.

> [I]ts [solar geoengineering's] direct climatic effects would be largely reversible (National Research Councils [28, p. 48]). Models indicate that, all things being equal, temperature and precipitation would re-equilibrate or return to previous conditions within months or a couple years following a reduction or cessation of solar geoengineering activity. (Reynholds & Horton [94, p. 2].)

> Sulfates do not reproduce. If you stop injecting them they will disappear from the stratosphere in a few years. (Keith [63, p. 12].)

References: Gardiner [37], Keith [63], MacMartin et al. [75], Reynolds & Horton [94].

4.6 Cost-efficiency (SP)

Typical target(s): Research and deployment.
Scope: Geoengineering in general, but mostly centered in SAI.
Attacks: **Economic costs** 3.9.

Description. The main idea: certain forms of geoengineering, chiefly among them SAI, are highly cost-efficient (which increases their feasibility relative to other answers to the climatic crisis). It is even said that the benefits have a high enough chance (61%) of outweighing the costs.

> Solar geoengineering's direct financial costs of implementation are presently estimated to be as low as 2.25 billion US dollars annually (...) This is inexpensive compared to the costs of either aggressive mitigation or climate change damages, each of which could annually be trillions of US dollars. (Reynolds & Horton [94, p. 2].)

> The economics of geoengineering are—there is no better word for it—incredible. (...) [A]dding stratospheric aerosol dust to the stratosphere would cost just pennies per ton of CO2 mitigated. (Barret [5, p. 49].)

References: Barrett [5], Gardiner [37], Smith & Wagner [108], Reynolds & Horton [94], Smith [105], Smith et al. [106], Harding et al. [41],

4.7 Towards climate justice (SP)

Other name(s): **Warming mitigation in tropical countries**.
Typical target(s): Research and deployment.
Scope: Geoengineering in general.
Attacks: **Inequity increase** 3.4.

Description. The general idea is that implementation of geoengineering might contribute to overall climate justice. There are at least two variations of this idea:

1. **International justice**. It is claimed that certain forms of geoengineering (most prominently SAI)—could be particularly effective in mitigating warming in tropical and developing nations. These regions suffer the most damage from climate change, while historically they have benefited the least from global carbon emissions. Consequently, the implementation of geoengineering could serve as a mechanism for international justice.

   > Based on these arguments demonstrating both that adaptation and solar geoengineering are capable of benefiting today's poor in ways that mitigation cannot and that the benefits from SRM compared to adaptation are cheaper, more global in scale and effect, and more reliant on the realistic assumption of self-interested behaviour, we conclude that a prima facie moral obligation exists to investigate the potential of SRM to help the developing world. (Horton & Keith [46, p. 84].)

2. **Intergenerational justice**. By living in fossil-fuel driven economies, we pass on a carbon-debt to future generations. It is claimed that geoengineering can be a method to alleviate the effects of that debt, thus improving intergenerational justice.

   > [G]eoengineering research emerges as one way of assisting future generations. If the world really isn't going to do very much about reducing emissions, then substantial investment in geoengineering research emerges as an alternative way in which we can meet our intergenerational obligations. (Gardiner [37, p. 7].)

References: Gardiner [37], Horton & Keith [46], Neuber & Ott [85, p. 2], Smith & Henley [107, p. 8], Keith & Visioni [60].

4.8 Saving of human lives (EN)

Typical target(s): Research and deployment.
Scope: Geoengineering in general (but most prominently SAI).
Attacks: **Health risks** 3.12.

Description. The idea is that geoengineering technologies might help to prevent temperature-attributable human mortality. So far, this has been specially studied for the case of SAI.

> [W]e estimate that, in a world 2.5 °C warmer than preindustrial, 1 °C of global average cooling by SG reduces mortality by over 400,000 deaths annually by 2080. (...) Mortality decreases in many hot, poor regions and increases in some cold, rich regions. We estimate the mortality benefits of reducing temperatures outweigh risks from air pollution and from ozone loss by 13 times for our central estimates. (Harding et al. [41, p. 1].)

References: Eastham et al. [34], Harding et al. [41], Adelity et al. [2].

4.9 Risk profile (EN)

Typical target(s): Research and deployment
Scope: Geoengineering in general.
Attacks: **Economic costs** 3.9, **Termination shock** 3.6, **Effects on regional climates** 3.10, **Harms to the biosphere** 3.11, **Health risks** 3.12, **Less sun for solar power** 3.13.[10]

Description. The general idea is that the risk profile of geoengineering interventions is favorable compared to that of non-deployment scenarios. This is either because the risks discussed in Sect. 3 have been overstated or because they can be prevented through appropriate intervention design.

1. **Risk overstatement.** It is claimed that some of the potential risks have been overstated. The argumentation proceeds by showing that the effects of using SRM are not as violent as it had been thought, and that interventions can be optimized both in their magnitude and temporal profile.

   > The use of particles engineered to exploit photophoretic forces may enable more selective geoengineering with fewer adverse effects than would the use of sulfate aerosol. Further, the ability to orient particles and to achieve long atmospheric lifetimes might enable deployment of more spectrally selective scattering systems... (Keith [62, p. 16430].)

2. **Cocktail geoengineering** (aka. **Ensemble strategy**). The idea is that many of the risks or drawbacks of specific forms of geoengineering (e.g. SAI) can potentially be avoided by combining different forms of geoengineering (together, of course, with CO_2 emissions reduction) in an optimal way.[11] .

   > [I]njection of sulfate aerosols into the stratosphere [viz. SAI] can cool climate, but (...) cannot simultaneously globally restore both average temperatures and average precipitation. It has also been suggested that the Earth could be cooled by thinning cirrus clouds (...) Our climate modeling study shows, for the first time, that a cocktail of these two approaches would decrease precipitation and temperature in the same ratios as they are increased by CO2, which would allow simultaneous recovery of preindustrial temperature and precipitation in a high CO2 world at global scale. (Cao et al. [17, p. 7429].)

References: Keith [62], Moreno-Cruz et al. [81], Dykema et al. [33], Cao et al. [17], Parker & Irvine [89], Tilmes et al. [118], Dagon & Schrag [31], Soldatenko & Yusupov [111], Irvine et al. [54], Adeliyiti et al. [2].

[10] Notice that, indirectly, this could also be a response to **Unascertained results** 3.16 since some of the gaps in knowledge of the consequences of some strategies could be filled by the knowledge regarding other forms of geoengineering.

[11] This strategy is pursued with particular emphasis by the *Geoengineering Large Ensemble Project (GLENS)*. See Tilmes et al. [118], as well as the website: `https://www.cesm.ucar.edu/community-projects/glens.`

5 Conclusions

So far, our project has been to analyze the different arguments regarding geoengineering. Our aim here was to dissect and group into broad (and subgroups of specific) categories the arguments against and in favor of geoengineering found in the literature. Figure 2 below exhibits the different arguments against geoengineering we considered, classified by their family. Figure 3 presents the arguments in favor of it, classified accordingly. Finally, Figure 4 presents the Attack connections between the arguments.

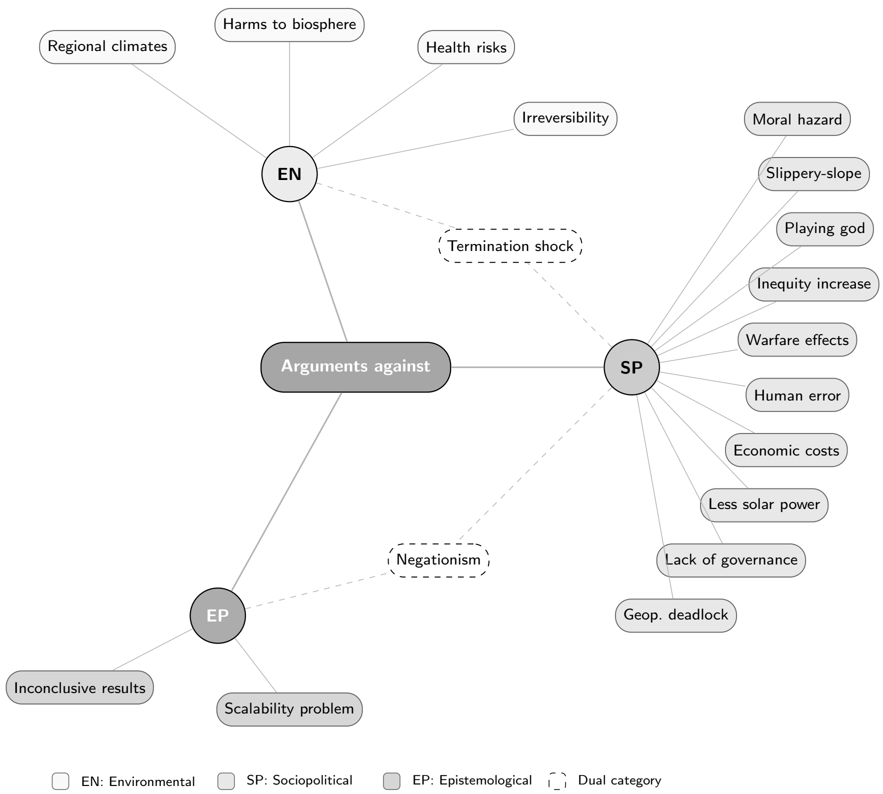

Figure 2: Arguments against geoengineering, classified by family.

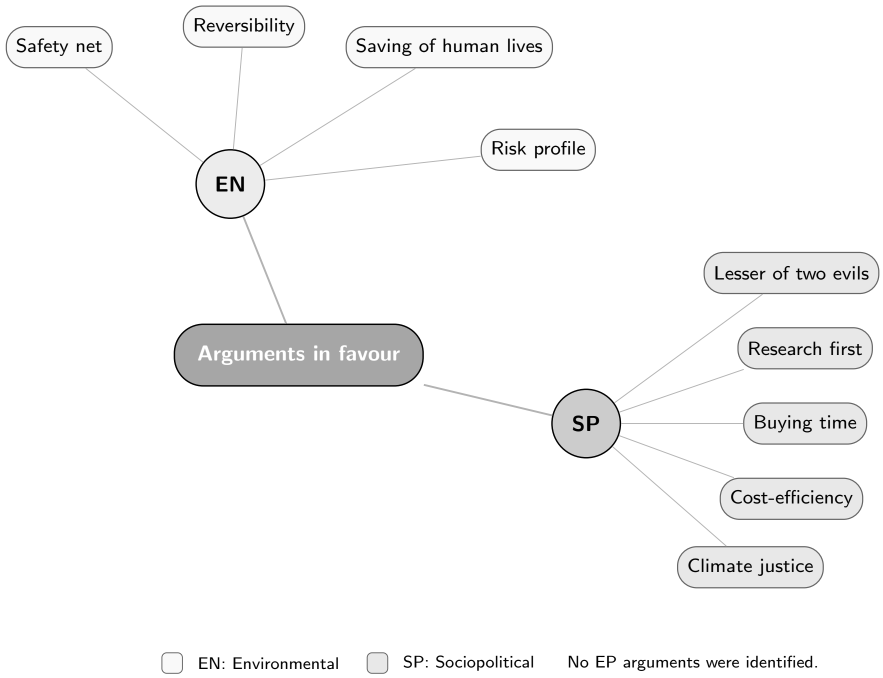

Figure 3: Arguments in favor of geoengineering, classified by family.

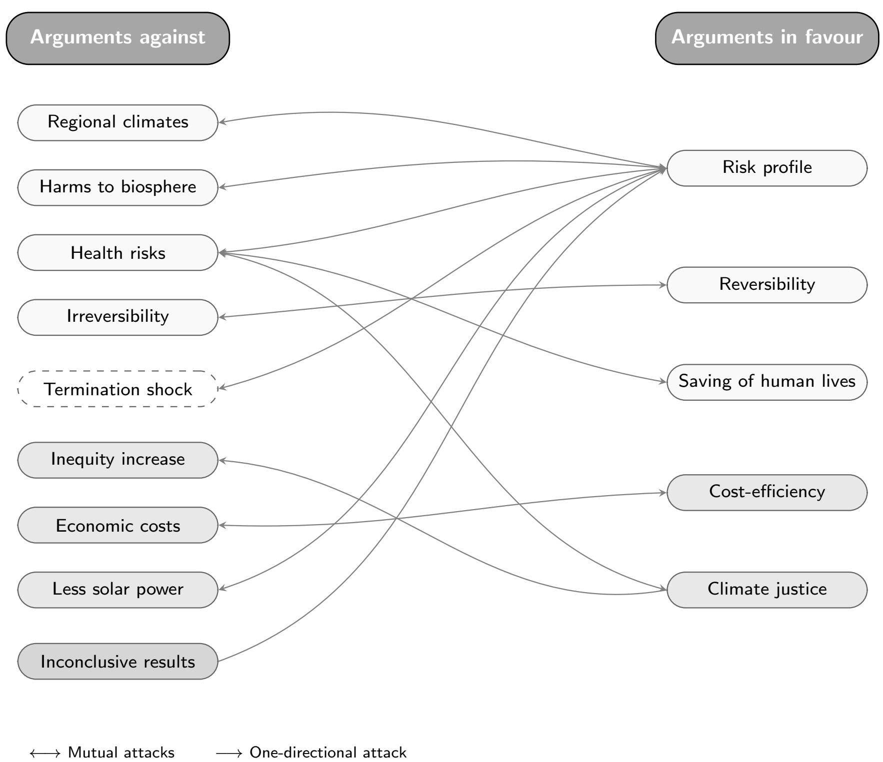

Figure 4: Attack connections between arguments against and in favor of geoengineering. Bidirectional arrows indicate mutual attacks; single arrows indicate one-directional attacks.

The methodology was mainly a descriptive one: we gathered all the arguments present in academic and institutional sources, and proceeded to categorize them into their respective families with no evaluation of what strategies are at play. As future work, we hope to build on this map to assess the relative weight of the arguments identified and to examine more closely the logical connections between them.

6 Appendix A: Argument Reconstruction

An argument reconstruction is the analytical process of identifying, extracting, and explicitly stating the logical structure of a reasoning originally expressed in a fragmented or implicit manner. While the original formulation in natural language is often "enthymematic"—relying on unstated premises, rhetorical devices, or non-linear sequences—–the reconstruction acts as a translation into a canonical format (typically a series of numbered premises leading to a conclusion) to reveal its inferential skeleton.

Due to natural language being inherently polysemic, it is entirely possible to produce diverse reconstructions of the same argument; a researcher might prioritize a deductive interpretation to test for validity, while another might choose an inductive framing to better reflect the author's original intent under the principle of charity. Ultimately, reconstructing arguments is a vital tool for critical evaluation: it allows us to isolate the specific logical leaps, identify hidden fallacies, and determine whether a conclusion—–such as the moral objection to geoengineering—–is genuinely supported by its foundations or remains a mere non-sequitur.

As we mentioned, the primary objective of this report has not been to generate a formal reconstruction of each argument for and against the subject. Instead, our purpose lies one step prior: to provide the most comprehensive conceptual overview possible of the main arguments surrounding the debate. We expect the map we offered to help researchers and policymakers on SRM, more broadly, make informed decisions. The review provides input for this, but it cannot be the only one; evaluative work remains necessary. Reconstructions imply a step in the direction of adequately assessing arguments. By way of example, we offer the following two reconstructions:

The Moral Hazard:

- P1: Humanity has a moral obligation to mitigate anthropogenic climate change by reducing greenhouse gas emissions at a sufficiently rapid rate.
- P2: Effective mitigation requires strong political will, sustained public commitment, and substantial investment in emission-reduction policies.
- P3: If a technological intervention appears to offer a relatively low-cost and low-risk solution to climate change, political actors and societies may become less motivated to pursue difficult mitigation policies.
- P4: Geoengineering is often presented as a technological intervention that could potentially offset climate warming at relatively low cost.
- P5: Therefore, knowledge of, research into, or deployment of geoengineering may weaken the political will to pursue emission mitigation.
- P6: If political will for mitigation is weakened, mitigation efforts may occur more slowly or at a lower level than morally required.
- Conclusion: Therefore, the development or deployment of geoengineering risks producing mitigation deterrence, and for that reason, constitutes a serious moral and policy objection to geoengineering.

The second example undergoing reconstruction is one of the supporting arguments:

The Safety Net:

- P1: Global efforts to curb greenhouse gas emissions (Plan A/Mitigation) are currently inadequate or may fail to prevent reaching climatic tipping points.
- P2: If Plan A fails or is inadequate, the result will be a "dystopian vision" of rapid, dangerous climate change and extreme climatic instability.

- P3: Climate engineering (Plan B) is a technically feasible means—though characterized by significant uncertainty and environmental risk—to potentially avoid or mitigate the harms of such a dystopian scenario.
- P4: It is better to have a high-risk fallback option (a "safety net" or "hedge") than to face a catastrophic climatic outcome without any recourse.
- P5: (Implicit/Structural) A research program is a necessary condition for the availability and viability of Plan B as a functional fallback option.
- Conclusion: Therefore, it is desirable to establish a research program into climate engineering technologies, framed not as a replacement for mitigation, but as a reluctant "Plan B."

7 Appendix B: Methodological details

This appendix provides a detailed account of the methodological choices underlying the present review, including the rationale for the label *analytical review of reasons* and a comparison with related approaches.

7.1 Analytical Review of Reasons.

Those familiar with the model proposed by Strench and Sofaer [113] for systematic reviews of reasons will find broad similarities with our work: the guiding question is factual rather than directly normative, arguments are classified into types, and their connections are assessed. However, we depart from the full systematic review in several respects. We did not construct database-specific search strings using controlled vocabulary, nor did we produce flow charts documenting the selection process from an initial pool of retrieved publications. The classification was not conducted entirely independently by separate reviewers.

In place of those procedures, we relied on a pluralist source identification strategy, as described above. A multi-author review that reaches consensus through collective discussion is plausibly more robust than a typical single-author informal review based on undocumented research. Moreover, the broad criterion adopted is particularly important, given that the most frequently published arguments are not necessarily the strongest ones—they might simply be the best publicized, involving conflicts of interest or blind spots [114]. A broad search strategy gives less prominent reasons equal voice before any direct appraisal.

Our review also distinguishes itself from narrative reviews, as described by Sukhera [115]. Narrative reviews include interpretations and criticisms, synthesize different points of view, remain open to new insights, and provide critical synthesis in the analysis. Sukhera's *meta-narrative review:* "... seeks to explore and make sense of contradictions and tensions within the literature. A meta-narrative review maps how a certain topic is understood in distinct ways [...], and then seeks to make sense of how such narratives are interpreted across different disciplines or historical contexts, as part of the analysis." (p. 416).

Our review, by contrast, seeks to expose arguments and map their connections; any tensions that emerge do so from the structure of the arguments themselves. We do not explicitly compare across disciplines or historical contexts. In this sense, our aim is closer to a description. Narrative reviews are free of the requirement to incorporate all relevant literature on the topic, but demand the use of search terms in database searches, which our approach does not employ in the strict sense.

Our methodology combines elements of systematic review of reasons and narrative reviews, while distinguishing itself from both. To avoid using a label associated with a framework we do not fully adopt, we opt for the label *analytical review of reasons*. This label is intended to reflect the central feature of our approach: we address arguments by analyzing them across several aspects and examining how they fit into broader families, aiming to present them and make their connections explicit so that the result is not merely a list but rather a navigable network.

We attempted, though we cannot guarantee, complete coverage of the literature. We acknowledge this as a limitation, as reasons present in the literature may well have been missed. However, the present review offers a reasonably broad and diverse map of the argumentative landscape. A review of this kind is likely to identify a wider variety of reasons than searches typically conducted by individual authors of informal reviews or official reports. Beyond the classification itself, a review of this kind can reveal trends in the use of arguments across the literature, lead to the identification of assumptions, and flag areas where further research is needed.

When classifying arguments, some choices must be made. For instance, when giving arguments their names, we sometimes adopt names from the literature, whereas in other cases we coin new names to better convey their main ideas. Since arguments in the literature often circulate under different labels—sometimes reflecting conceptual distinctions, sometimes merely terminological variation—we adopted the following convention: each argument is presented under a single main name, chosen on the basis of representativeness or prevalence in the literature, and alternative names are listed under *Other name(s)*. This is not a glossary of synonyms: in some cases, the alternative names carry different connotations or emphasize different aspects of the argument. We flag such cases in their respective description. The process of reviewing reasons entails unavoidable interpretational decisions; we address these by making it clear when a decision is being made.

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