McMaster University | Health Forum

Rapid Evidence Profile Appendices

Reviewing the landscape of literature on solar radiation modification

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Appendices

Appendix 1: Methodological details

We use a standard protocol for preparing rapid evidence profiles (REP) to ensure that our approach to identifying research evidence is as systematic and transparent as possible in the time we were given to prepare the profile.

Identifying research evidence
For this REP, we searched Social Systems Evidence, Web of Science, and Scopus for evidence syntheses.

We searched Social Systems Evidence using an open text search: “solar radiation modification” “stratospheric aerosol injection” “solar geoengineering” “climate engineering”.

We ran a second in Web of Science using: (((((((((TS=(“Solar Radiation Modification”)) OR TS=(“solar radiation management”)) OR TS=(“stratospheric aerosol injection”)) OR TS=(“solargeoengineering”)) OR TS=(“climate engineering”)) OR TS=(“climate intervention”)) OR TI=(albedo* AND (modification or increas* or alteration))) OR TS=(“marine cloud brightening”)) OR TS=(“cirrus cloud thinning”)) OR TS=(“Spaces mirrors”)) OR TS=(“Space sunshades”).

We ran a third search in GEOBASE and GeoReference using: (((((((((((“Solar Radiation Modification”) WN KY) OR ((“solar radiation management”) WN KY)) OR ((“stratospheric aerosol injection”) WN KY)) OR ((“solar geoengineering”) WN KY)) OR ((“climate engineering”) WN KY)) OR ((“climate intervention”) WN KY)) OR ((albedo* AND (modification or increas* or alteration)) WN TI)) OR ((“marine cloud brightening”) WN KY)) OR ((“cirrus cloud thinning”) WN KY)) OR ((“Spaces mirrors”) WN KY)) OR ((“Space sunshades”) WN KY)).

Finally, we ran a fourth search in SCOPUS using: (TITLE-ABS-KEY (“Solar Radiation Modification”) OR TITLE-ABS-KEY (“solar radiation management”) OR TITLE-ABS-KEY (“stratospheric aerosol injection”) OR TITLE-ABS-KEY (“solar geoengineering”) OR TITLE-ABS-KEY (“climate engineering”) OR TITLE-ABS-KEY (“climate intervention”) OR TITLE (albedo* AND (modification OR increas* OR alteration)) OR TITLE-ABS-KEY (“marine cloud brightening”) OR TITLE-ABS-KEY (“cirrus cloud thinning”) OR TITLE-ABS-KEY (“Spaces mirrors”) OR TITLE-ABS-KEY (“Space sunshades”)).

Links provide access to the full search strategy. We are unable to provide a link to the GEOBASE/GeoReference or Scopus searches as they are linked to institutional accounts.

Each source for these documents is assigned to one team member who conducts hand searches (when a source contains a smaller number of documents) or keyword searches to identify potentially relevant documents. A final inclusion assessment is performed both by the person who did the initial screening and the lead author of the rapid evidence profile, with disagreements resolved by consensus or with the input of a third reviewer on the team. The team uses a dedicated virtual. channel to discuss and iteratively refine inclusion/exclusion criteria throughout the process, which provides a running list of considerations that all members can consult during the first stages of assessment. Excluded documents are listed in Appendix 6. The team has also included a PRISMA diagram in Appendix 7 to help illustrate the state of the literature and particular inclusion decisions.

During this process we include published, pre-print, and grey literature, but we did not undertake a specific search for either pre-print or grey literature. We do not exclude documents based on the language of a document. However, we are not able to extract key findings from documents that are written in languages other than Chinese, English, French, Portuguese, or Spanish. We provide any documents that do not have content available in these languages in an appendix containing documents excluded at the final stages of reviewing.

Assessing relevance and quality of evidence

We assess the relevance of each included evidence document as being of high, moderate, or low relevance to the question.

Two reviewers independently appraised the quality of the guidelines we identified as being highly relevant using AGREE II. We used three domains in the tool (stakeholder involvement, rigour of development, and editorial independence) and classified guidelines as high quality if they were scored as 60% or higher across each of these domains.
Two reviewers independently appraise the methodological quality of evidence syntheses that are deemed to be highly relevant using the first version of the AMSTAR tool. Two reviewers independently appraise each synthesis, and disagreements are resolved by consensus with a third reviewer if needed. AMSTAR rates overall methodological quality on a scale of 0 to 11, where 11/11 represents a review of the highest quality. High-quality evidence syntheses are those with scores of eight or higher out of a possible 11, medium-quality evidence syntheses are those with scores between four and seven, and low-quality evidence syntheses are those with scores less than four. It is important to note that the AMSTAR tool was developed to assess evidence syntheses focused on clinical interventions, so not all criteria apply to those pertaining to health-system arrangements or implementation strategies. Furthermore, we apply the AMSTAR criteria to evidence syntheses addressing all types of questions, not just those addressing questions about effectiveness, and some of these evidence syntheses addressing other types of questions are syntheses of qualitative studies. While AMSTAR does not account for some of the key attributes of syntheses of qualitative studies, such as whether and how citizens and subject-matter experts were involved, researchers' competency, and how reflexivity was approached, it remains the best general quality-assessment tool of which we're aware. Where the denominator is not 11, an aspect of the tool was considered not relevant by the raters. In comparing ratings, it is therefore important to keep both parts of the score (i.e., the numerator and denominator) in mind. For example, an evidence synthesis that scores 8/8 is generally of comparable quality to another scoring 11/11; both ratings are considered 'high scores.' A high score signals that readers of the evidence synthesis can have a high level of confidence in its findings. A low score, on the other hand, does not mean that the evidence synthesis should be discarded, merely that less confidence can be placed in its findings and that it needs to be examined closely to identify its limitations. (Lewin S, Oxman AD, Lavis JN, Fretheim A. SUPPORT Tools for evidence-informed health Policymaking (STP): 8. Deciding how much confidence to place in a systematic review. *Health Research Policy and Systems* 2009; 7 (Suppl1): S8.)

Preparing the profile

Each included document is cited in the reference list at the end of the REP. For all included guidelines, evidence syntheses and single studies (when included), we prepare a small number of bullet points that provide a summary of the key findings, which are used to summarize key messages in the text. Protocols and titles/questions have their titles hyperlinked, given that findings are not yet available.

We then draft a summary that highlights the key findings from all highly relevant documents (alongside their date of last search and methodological quality).

Upon completion, the REP is sent to a subject-matter expert for their review.

Appendix 2: Details about each identified evidence synthesis

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Living status	Quality (AMSTAR)	Last year literature searched	Availability of GRADE profile	Equity considerations

• Methods of solar radiation modification
  ○ Stratospheric aerosol injections
  ○ Cirrus cloud thinning
  ○ Marine cloud brightening
  ○ Space mirrors
• Benefits or harms of solar radiation modification
	Existing atmospheric, hydrospheric, and cryospheric geoengineering techniques can lead to decreased sea-level rise, but optimal implementation will require thoughtful consideration of complex atmospheric effects and the coordination and alignment of techniques (1)
	• The evidence synthesis examines the extent to which atmospheric, hydrospheric, and cryospheric geoengineering techniques can lead to decreased sea-level rise.
	• Though the evidence synthesis provides transparent methods, no approach for assessing the quality of included evidence documents has been used and similarly the table of included studies does not include methods of the included literature.
	• The evidence synthesis found that, if implemented at a moderate intensity, stratospheric aerosol injection could impede radiative forcing from greenhouse gases but may result in enhanced precipitation variability over the oceans and excessive cooling effects in some areas.
	• Similarly, cirrus cloud thinning can decrease atmospheric temperatures, but can also lead to more warming in the stratosphere and change the complex atmospheric circulation.
	• The evidence synthesis found that marine cloud brightening technique can inhibit sea level rise, but it is limited by the available of stratocumulus clouds that are currently in only 10% of the Earth's surface.
	• Finally, for sea ice restoration, it is unclear how the reflective materials could impact local fauna and there is a lack of mainstream policy support for ice restoration techniques.
		High	No	2/9	Published June 2023	No	• None identified

• Methods of solar radiation modification • Benefits or harms of solar radiation modification	Given the evolving dynamics of the ethics of geoengineering, evidence suggests that there has been a gradual shift in more recent years from the initial favouring of geoengineering to a more cautionary endorsement considering the challenges identified (2) • Major opportunities in geoengineering include confronting the climate emergency, creating cost-effective options to address climate change, facilitating new opportunities for research as well as public engagement, and developing an alternative to the worst-case scenario of human extinction. • Major challenges of geoengineering include unequal distribution of costs, benefits, and harms to vulnerable populations and future	High	No	2/9	January 2020	No	• Vulnerable populations

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Living status	Quality (AMSTAR)	Last year literature searched	Availability of GRADE profile	Equity considerations
	generations, the complexity of developing an adequate governance mechanism, irreducible uncertainties with geoengineering techniques, concerning risks of large-scale trans-boundary interventions, moral hazard challenges, and ecological challenges.						
• Solar radiation modification ○ Stratospheric aerosol injections • Benefits or harms of solar radiation modification	Solar Radiation Modification (SRM) geoengineering methods literature largely reliant on modelling studies, suggests that they could weaken the hydrologic cycles (e.g., the continuous circulation of water in the Earth-Atmosphere system) by reducing precipitations, while Stratospheric Aerosol Injection (SAI) might be the most effective technique in reducing global warming with minimal evaporation change (3) • The size of prescribed aerosol particles to be injected as well as their altitude and latitudinal precipitation may vary resulting in different calculations of reduced precipitation. • SAI is the SRM technique mostly studied in the literature, in which the stratosphere is injected with sulphate particles, making solar radiation reflected. • Studies suggest that greenhouse effects would be larger if SAI is conducted at lower altitude with larger aerosol particles.	High	No	2/9	2023	No	• No
• Methods of solar radiation modifications • Benefits or harms of solar radiation modifications • Equity considerations ○ Countries in the Global South	A review exploring the social, economic, and ethical implications of deploying SRM techniques concludes that solar geoengineering will likely cause a decrease on the potential of renewable energies (4) • SRM techniques can be divided into those with global impact (e.g., reflective mirrors in space) and those with a more local impact (e.g., painting urban surfaces white), and in their aim to modify atmospheric albedo. • Solar geoengineering is likely to have effects on the renewable energy potential, and mostly to solar energy, biomass energy, hydro energy, and wind energy. • Due to the reduction on the need to lower carbon emissions, solar geoengineering might delay the transition and uptake to renewable energies.	High	No	2/9	2022	No	• Place of residence
• Methods of solar radiation modifications • Governance of solar radiation modifications • Ethical implications • Equity considerations	Solar geoengineering (SG) literature is dominated by research supporting its implementation or application and mainly focusing on decision-making aspects, neglecting cultural and ethical dimensions (5) • Solar geoengineering literature is dominated by research supporting its implementation or application, rather than discussion papers presenting research and discussion around it. • Solar geoengineering literature is mainly focusing on informing decision-making, but they do not provide concrete guidance on how they can do so.	High	No	1/9	2024	No	• None reported

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Living status	Quality (AMSTAR)	Last year literature searched	Availability of GRADE profile	Equity considerations
○ Countries in the Global South ○ Countries that are disproportion-ately impacted by climate change							
• Methods of solar radiation modification ○ Stratospheric aerosol injections	The identification and quantification of uncertainties varies greatly in studies on stratospheric aerosol injections, but it is improving overtime and the literature is paying more attention to uncertainty estimations (6) • This evidence synthesis examines how published research on stratospheric aerosol injection models establish and communicate confidence and uncertainties. • The synthesis notes three main sources of uncertainty: model uncertainty, scenario uncertainty, and uncertainty related to internal climate variability. • Model performance and perceived accuracy can be examined by looking at the model fit (how well the model matches to observational data) and the robustness (how well the model results agree with other models). • The synthesis focused on model uncertainty and uncertainty related to internal climate variability as included articles used non-standardized scenarios and lacked quantitative scenario uncertainty estimations. • Approximately one-third of the reviewed articles were using more than one model in order to explore model uncertainty, often using a multi-model ensemble; however, perturbed physical ensemble and sensitivity analysis were occasionally used in older models. • For natural variability uncertainty, the use of initial condition large ensembles was rare in the sample and scenario uncertainty was not analysed in the study.	High	No	4/9	February 2021	No	• None reported
• Methods of solar radiation modification • Benefits or harms of solar radiation modification • Ethical implications	Literature on climate geoengineering has grown exponentially; however, very little of it is empirically based and the majority of it embraces a dual high-stake framing, advocating for careful research without fully embracing or rejecting these new technologies (7) • The evidence synthesis reviews the climate geoengineering literature between 2006 and 2013, noting a substantial increase in the volume of literature, particularly in those related to natural science though also relevant to social sciences in later years.	Medium	No	1/9	2013	No	• None reported

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Living status	Quality (AMSTAR)	Last year literature searched	Availability of GRADE profile	Equity considerations
	• The synthesis notes that modelling studies dominate the natural science papers and only about a quarter of the included literature had noted methods, with even fewer citing actual field studies; rather the majority included focus group interviews, game theory analysis, ethical analysis, argumentation analysis, and discourse analysis. • The body of literature saw increases in publications on solar radiation modification as well as carbon dioxide removal, with many more addressing solar radiation modification. • Much of the included literature positioned the risks and benefits as being catastrophic on both sides. • Many of the included recommendations from the examined literature focused on next steps in research.						
• Methods of solar radiation modification • Views and experiences	Studies examining public opinion about geoengineering highlight a lack of widespread knowledge about approaches, significant concerns about the risks of geoengineering, and the perceived need for a governance framework for both research, testing, and deployment (8) • The evidence synthesis aims to review the public perceptions of geoengineering, including solar radiation modification, carbon dioxide removal, and carbon capture and storage. • The synthesis aims to support the use of adaptive and anticipatory governance, which can be improved through engagement of the public to identify implications on human and environmental health as well as to understand the level of acceptance among stakeholders. • Of the included literature, about half included quantitative data from surveys or experimental designs, while the rest use qualitative approaches including interviews and focus groups. • As a first theme, the synthesis identified that few people were familiar with geoengineering, particularly with stratospheric aerosol injection. • The second theme noted that many members of the public were intrigued by the benefits of geoengineering but risks associated with their use reduced public support; findings included: ○ the public perceived more risk than benefit from geoengineering, particularly from solar radiation modification ○ while some benefits were noted, the public generally believed that we should hold off until other mitigation efforts become insufficient ○ the public participants in particular studies noted a benefit of stopping climate emergencies using solar radiation modification and being cheaper than stopping the use of fossil fields	High	No	4/9	2015	No	• None reported

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Living status	Quality (AMSTAR)	Last year literature searched	Availability of GRADE profile	Equity considerations
	◦ carbon dioxide removal was generally preferred over solar radiation modification methods, as it is viewed as more natural and in sync with the environment. • Though there is little support for its use, the public provided strong support for continued laboratory research for solar radiation modification but not for field testing. • Many of the included studies called on the development of international governance approaches for research, testing, and any future deployment.						
• Methods of solar radiation modification	Through bibliometric analysis of climate engineering research from 1988 to 2011, the study revealed that SRM publications emerged as a significant focus area, particularly after 2006, with a notable surge between 2006 and 2009; however, SRM represented a smaller portion (approximately 26%) of total climate engineering publications compared to CO_2 removal methods, and SRM research groups tended to work relatively independently with limited collaboration across different methods (9)	High	No	2/9	2011	No	• None reported

Appendix 3: Details about each identified single study

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
• Methods of solar radiation modification ○ Stratospheric aerosol injections	The researchers propose SCoPEx as a small-scale stratospheric experiment to study key uncertainties in solar radiation modification (SRM), specifically focusing on how sulfate aerosols would interact with stratospheric chemistry and affect ozone, while emphasizing the need for rigorous oversight and the experiment's deliberately limited scale compared to actual SRM deployment (10) • The experiment proposes using a propelled balloon system at ~20km altitude to create a small, perturbed volume in the stratosphere by injecting sulfate aerosols and water vapour. • The study explicitly notes that SCoPEx's unique propelled balloon design would allow controlled study of aerosol microphysics and chemical interactions without meaningfully advancing deployment capabilities. • The study emphasizes that despite the experiment's small scale, it would only proceed with independent risk assessment, public funding, and full transparency, given the controversial nature of SRM research.	High	Publication date: 2014 Jurisdiction studied: United States, Sweden Methods used: Stratospheric controlled perturbation experimental design	• No
• Methods of solar radiation modification ○ Marine cloud brightening • Benefits or harms of solar radiation modification	SRM efforts in Australia's Great Barrier Reef involve two main approaches: 1) localized fogging that provides temporary shading for hours to days using small water particles sprayed from ships, and 2) marine cloud brightening that aims to cool larger reef areas for weeks to months by spraying salt particles to increase cloud reflectivity, though this technology is still about 10 years away from deployment readiness (11) • Both fogging and cloud brightening deploy particles from ships, but use different nozzle types and particle sizes for localized versus regional effects. • Models show cloud brightening could significantly reduce heat stress, with fogging effects lasting hours to days and cloud brightening effects potentially lasting weeks to months. • Scaling difficulties (cloud brightening would need to cover half the Great Barrier Reef), high energy requirements, complex regulations, challenges measuring effectiveness, limited public engagement, and estimated high costs are key hurdles for both approaches. • Potential negative impacts include altered inland forest precipitation, effects on coastal ecosystems and water tables, weather pattern changes affecting agriculture, and uneven spatial protection.	High	Publication date: 2023 Jurisdiction studied: Queensland, Australia, Methods used: Qualitative case study	• None reported

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
• Methods of solar radiation modification	The B²SAP project establishes baseline measurements of stratospheric aerosol properties using balloon-borne instruments, demonstrating the ability to detect and characterize both natural and potential anthropogenic perturbations to stratospheric aerosols (12) • By tracking aerosol concentrations from ground level to 28km above Boulder, Colorado, researchers documented stable baseline conditions where particle concentrations typically vary by just 2–4 times. • This stability makes perturbations readily detectable, as demonstrated when the Raikoke and La Soufrière volcanic eruptions produced 10-fold increases in aerosol concentrations. • These events showcased distinct patterns – Raikoke's larger SO_2 injection led to both increased particle numbers and larger particle sizes, while La Soufrière primarily affected smaller particle concentrations. • The study demonstrates capabilities to track and measure changes in aerosol concentration, size distribution, and optical properties – key parameters for assessing radiative impacts. • This research establishes methodology for long-term monitoring at multiple global sites that could help evaluate any future stratospheric aerosol injection (SAI) efforts as a climate intervention strategy.	High	Publication date: 2023 Jurisdiction studied: United States, New Zealand Methods used: Observational study with longitudinal data collection	• None reported
• Methods of solar radiation modification • Benefits or harms of solar radiation modification	Surface albedo modification (SAM) using hollow glass microspheres (HGMs) shows potential as a localized solar radiation modification approach to help preserve Arctic ice, with experimental results demonstrating a 29% increase in surface reflectivity and corresponding reduction in ice melt rates when applied to pond ice (13) • The experimental results showed a substantial increase in average daily albedo from 0.17 to 0.36, leading to a 29% reduction in radiative energy absorption and a 33% reduction in ice volume melt rate. • Unlike global-scale solar radiation modification approaches, SAM can be implemented within territorial boundaries without requiring extensive international coordination, poses fewer governance and safety concerns, and represents a status quo preservation approach rather than an alternative to emissions reduction. • The study validated both durability and effectiveness of HGMs through winter conditions, demonstrating survival through snowfall and high winds while maintaining reflective properties post-snow melt. • The study confirms SAM's mechanism for ice preservation by targeting the ice albedo feedback loop specifically, showing that a 30% reduction in radiative energy leads to proportional reduction in ice melt rate, suggesting potential for scaled implementation in Arctic environments.	High	Publication date: 2022 Jurisdiction studied: United States Methods used: Experimental design	• None reported
• Methods of solar radiation modification ○ Stratospheric aerosol injections	Geoengineering experiments face a complex patchwork proponents and opponents who use a range of strategies to gain support for their perspective that have largely stalled field experiments for solar radiation modification (14)	High	Publication date: August 2022 Jurisdiction studied: Global	• Place of residence

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
○ Marine cloud brightening ○ Space mirrors • Governance of solar radiation modifications	• The study examines who defends and opposes early-stage experiments for 21 radical climate interventions including solar geoengineering approaches, marine cloud brightening, and stratospheric aerosol injection among others. • Marine cloud brightening was identified in three experiments E-PEACE, MCB Project and MCB Project for the Great Barrier Reef. ○ E-PEACE was not described as a field demonstration or geoengineering and so avoided opposition, but it did provide a proof of concept that marine cloud brightening is possible for some cloud conditions. ○ The Marine Cloud Brightening Project for the Great Barrier Reef (Reef Restoration and Adaption Program) is currently underway and provides an example of governance over this type of technology where an academic-like procedure was used with the investigator complying with all domestic environmental laws and acquiring the consent of Indigenous custodians. • Three projects of stratospheric aerosol injection are noted, but only one took place though it is highly controversial given it was done without any broader governance mechanisms. ○ The remaining two tests which were both part of wider research consortiums were stalled due to public and Indigenous opposition, but this provided the foundational case for the responsive research and innovation framework. • Common themes motivating controversy and opposition to experiments identified in the study include: ○ oppositional strategies from environmental non-governmental organizations include a standardized set of tactics focused on the delay of decarbonization, entrenched global inequities, and overly optimistic results ○ strategies supporting climate geoengineering include scientists emphasizing the small scale of their work, the use of academic procedures, and the use of governance frameworks such as those for responsible research and innovation ○ at times some experiments try to avoid ties to geoengineering and instead focus on having multiple beneficial outcomes beyond their climate impact (e.g., other adaptive strategies). ○ three groups have emerged that are critical to these experiments – institutional scientists, Indigenous actors, and entrepreneurial actors.		Methods used: Qualitative case study	
• Methods of solar radiation modification ○ Marine cloud brightening • Benefits or harms of solar radiation modification	Cumulus clouds that are dominant over the Great Barrier Reef in the summer appear to be amenable to marine cloud brightening (15) • The study reports on the first flight of a new airborne research laboratory to support the small-scale field experiment of marine cloud brightening in Australia. • The study provides considerable details about the aircraft and its instrumentation. • Measurements of aerosols and clouds, meteorological conditions, and sea-salt plumes were undertaken to determine whether the aircraft could act as a reliable platform to conduct measurements of marine clouds.	High	Publication date: August 2024 Jurisdiction studied: Australia Methods used: Case report	• Place of residence

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
	• The study found that both clean and polluted clouds formed over the reef and in particular that polluted clouds are travelled from mainland Australia to the reef and changing how clouds form and importantly that they produce less rain.			
• Methods of solar radiation modification ○ Stratospheric aerosol injections ○ Marine cloud thinning ○ Space mirrors • Views and perspectives • Equity considerations ○ Countries in the Global South	The actors involved in negative emissions and in solar radiation modification demonstrate diverse views with respect to their support and opposition, with less opposition to negative emissions as compared to solar radiation modification approaches (16) • The study uses expert interviews to examine the legitimacy of actors' potential decisions to deploy solar radiation modification technologies and the legitimacy of the technologies themselves. • The study includes 10 solar radiation modification options and highlights very limited support for solar engineering but a much broader and more valuable global market for negative emissions. • The most relevant social actors identified for solar engineering are governments, scientists, environmental non-governmental organizations, and civil society and innovation and industry. • In contrast innovation and industry followed by government and scientists are the most relevant interest groups for negative emissions. • The studies analysis of support for or opposition found that solar radiation modification and engineered approaches face unresolved controversy and are not as broadly supported as negative emissions technologies; further actors involved in solar radiation modification continue to focus on Global North, with the U.S. remaining at the epicentre of both technologies.	High	Publication date: August 2022 Jurisdiction studied: Global Methods used: Qualitative interviews	• Place of residence
• Methods of solar radiation modification	Data from volcanic eruptions shows that these events had substantial effects on sunlight and the amount of precipitation, which may affect agricultural yields (17) • Volcanic stratospheric sulfate aerosols (SSA) scattering would negatively affect yields, but only contemporaneous exposure to SSA matters for this effect. • Volcanic SSAs have substantial insolation-mediated costs that are similar in magnitude to their benefits from cooling, suggesting that SRM may not be able to reduce the impact of climate change on agricultural yields.	High	Publication date: August 2018 Jurisdiction studied: Global estimations based on data from Mexico and the Philippines Methods used: Simulations based on natural experiments	None reported
• Methods of solar radiation modification	Analyses from temperature data of three volcanic eruptions during the 1960s and 1990s showed inconsistencies in the magnitude of warming signals of the atmosphere, but a clear consistent atmospheric temperature response due to the eruptions (18) • Data from the Mount Pinatubo (Philippines) eruption suggests a strong warming signal in the tropical lower stratosphere, and a weak cooling signal in the subtropical upper troposphere.	High	Publication date: December 2015 Jurisdiction studied: Global estimations based on data from Mexico, the	No

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
	• Data from the El Chichón (Mexico) eruption suggests warming signals in the tropical lower stratosphere smaller than Mount Pinatubo's signals. • Data from the Mount Agung (Indonesia) eruption suggests an asymmetric temperature response in the equator with a strong warming signal in the Southern Hemisphere midlatitude upper troposphere to lower stratosphere.		Philippines, and Indonesia Methods used: Re-analyzing data from natural experiments of volcanic eruptions	
• Methods of solar radiation modification	A series of significant volcanic eruptions took place during 751–940 CE, which resulted in considerable changes to the climate in Europe as well as to Nile River flooding patterns (19) • Using ice core analysis from multiple sites in Iceland and Greenland the study examined a previously unrecognized period of intense volcanic activity in Iceland from 751–940 CE. • The study identified that there was much volcanic activity during this time period, leading to volcanic sulfate levels being 1.6 times higher than the previous period of volcanic activity. • The study also found that the volcanic eruptions it had an intense effect on weather leading to strong winter cooling across Europe and changes to the Nile River flooding patterns. • The paper notes that there was likely greater sensitivity to volcanic aerosols due to the absence of anthropogenic pollution.	High	Publication date: April 2024 Jurisdiction studied: Iceland, Greenland Methods used: Geological analysis (cyptotephra analyses, sulfur isotope analyses, and glaciochemical volcanic tracers)	None identified
• Methods of solar radiation modification	After making a relative comparison of the size of two major volcanic eruptions – El Chichón in April 1982 and Mount Pinatubo in June 1991 – researchers were able to conclude that Mount Pinatubo introduced less than twice (1.6 to 1.9) the amount of sulfuric acid aerosol particles into the stratosphere than El Chichón during the first three months following the eruptions; this indicates that Mount Pinatubo should have had nearly twice the climatic effects of El Chichón (20) • Aerosol optical thickness estimates were used to verify that the multi-channel sea surface temperature errors were related to aerosol particle concentration in the stratosphere.	High	Publication date: June 1993 Jurisdictions studied: Mexico Methods used: Cross comparative study	None identified

• Methods of solar radiation modification
  ○ Stratospheric aerosol injections
  ○ Marine cloud brightening
  ○ Space mirror
• Views and perspectives
	There is limited support for solar radiation modification technologies, particularly from high-income countries (21)
	• The study provides an overview of public support for climate change across 30 countries from an online survey of at least 1,000 participants per country on nine different technologies of which three were solar radiation modification (stratospheric aerosol injection, marine cloud brightening, and space-based geoengineering).
	• The study found that middle-income tended to support more extreme technologies such as solar radiation modification compared to high-income respondents, but both supported technologies that were perceived as more natural or ecosystem focused such as afforestation.
		High	Publication date: October 2024
			
			Jurisdiction studied: Global
			
			Methods used: Online survey
				• Place of residence
				• Age
				• Socioeconomic status

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
	• Of the solar radiation modification technologies, marine cloud brightening had the highest rate of support following by stratospheric aerosol injections and then space-based geoengineering. • Predictors of support included trust in industry, age (with older respondents showing less support), and expected personal harm from climate change, while environmental concern had a weaker correlation as compared to ecosystem-based approaches such as afforestation and reforestation or carbon sequestration.			
• Methods of solar radiation modification ○ Stratospheric aerosol injections ○ Marine cloud brightening ○ Space mirror • Views and perspectives	There is limited support for solar radiation modification technologies, particularly from high-income countries and older and wealthier populations (22) • The study provides an overview of public support for climate change across 30 countries and examines the demographics of support. • Solar radiation modification technologies received lower support than carbon removal options with stratospheric aerosol injection having the lowest mean support rating. • Support for solar radiation modification technologies declined significantly with age and there was greater support from the Global South and for those with lower socioeconomic status. • Minimal variation was found by gender with the exception of space-based geoengineering, which had slighter higher support among males.	High	Publication date: October 2024 Jurisdiction studied: Global Methods used: Online survey	• Place of residence • Age • Socioeconomic status • Gender/sex
• Methods of solar radiation modification ○ Stratospheric aerosol injections ○ Marine cloud brightening ○ Space mirror • Views and perspective ○ Countries in the Global South ○ Indigenous communities and people ○ Countries that are disproportionate impacted by climate change	Greater support was shown by Indigenous communities and minority respondents as compared to the remaining sample for solar radiation modification technologies when considered within strong governance frameworks (23) • A study using the same survey data examined the support for climate change across 30 countries among Indigenous communities. • Indigenous participants reported greater familiarity with climate engineering technologies and expressed more positive attitudes towards engineered options as compared to nature-based options, and particularly of small-scale trials • Indigenous and minority groups reported significantly more positive views about solar radiation modification than other respondents, with higher support from Turkey, India, Indonesia, Saudi Arabia, Nigeria, and Spain and lower support from Scandinavian countries. • Indigenous and minority respondents highlighted the need for a robust governance framework that is inclusive of diverse perspectives. • It should be noted that the number of respondents is quite low in each country, between three and 18 of 1,000 respondents, and as a result should be considered with caution.	High	Publication date: October 2024 Jurisdiction studied: Global Methods used: Online survey	• Ethnicity/race/culture
• Methods of solar radiation modification ○ Stratospheric aerosol injections	Focus groups from the Global South exhibit greater support but more considerable concerns for solar geoengineering, exhibiting strong support for multinational corporation, coordination, and public engagement in any research on solar geoengineering (24) • The study examines public perceptions on solar geoengineering from 44 focus groups in 22 countries with 323 participants.	High	Publication date: June 2024 Jurisdiction studied: Global	• Place of residence

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
○ Marine cloud brightening ○ Space mirrors • Views and perspective ○ Countries in the Global South	• Participants noted a juxtaposition on the relative importance of tackling the symptoms versus root cause of climate change, with Global South focus groups having stronger support for tackling symptoms, citing the need to dampen the severity of experienced impacts; however, some concern that it would detract from efforts to reduce emissions. • Participants from the Global South tended to see the global deployment as a positive while those from the Global North emphasized that planetary approaches can be a double-edged sword and as a result marine cloud brightening was most supported, given the potential to incrementally scale it. • Cited benefits were alleviation of heat stress and improving food security, while risks were unequal cooling and deeply uncertain knock-on environmental and societal effects (as well as concerns about the geopolitical agenda and the Global North shaping the deployment of these technologies). • Some concerns were raised regarding the infrastructure costs of solar geoengineering and questioned whether it represented a good investment. • A strong plurality of groups supported the conduct of small-scale field experiments, while some called for testing in uninhabited regions to minimize potential harms. • There was significant scepticism of giving leeway to advanced STEM industry actors and participants were concerned about latent profiteering and as a resulted supported the development of a global framework to govern the research and deployment of these technologies at the level of the UN or similar.		Methods used: Focus groups	
• Methods of solar radiation modification ○ Stratospheric aerosol injections ○ Marine cloud brightening ○ Space mirrors • Views and perspectives • Equity considerations ○ Countries in the Global South	Public opinion among students of solar radiation modification is consistent with other studies, with slightly greater support from countries in the Global South; however, it remains an unpopular option, with many believing that it will not address the cause of global warming and may result in harm to humans and the environment (25) • A public opinion online survey questionnaire of 4,583 student participants from 22 countries, most of whom studied social sciences and humanities, followed by engineering and natural sciences, and medical and health sciences. • In most countries, participants perceived solar radiation modification as being slightly effective in limiting global warming and generally participants believed very slightly that solar radiation modification would not address the causes of global warming; however, there was significant heterogeneity between clusters with countries in the Global North more strongly believing that they would not address the causes of global warming. • Participants generally thought that solar radiation modification would slightly reduce politicians' and citizens efforts to mitigate global warming, again with higher-income countries perceiving this more strongly. • Participants generally thought solar radiation modification would have slightly negative impacts on humans and nature with participants from the Global North citing greater concerns, but students particularly in Kazakhstan and Russia reported the highest level of concern.	High	Publication date: March 2024 Jurisdiction studied: Global Methods used: Online survey	• Place of residence

Dimension of organizing framework	Declarative title and key findings	Relevance rating	Study characteristics	Equity considerations
	• All participants felt the costs and benefits of solar radiation modification were unequally distributed across countries. • In general, the more people believed that solar radiation modification would have negative consequences or that it would not limit global warming the less they accepted it as an option.			
• Methods of solar radiation modification ○ Stratospheric aerosol injections ○ Marine cloud brightening ○ Space mirrors • Views and perspectives • Equity considerations ○ Countries in the Global South	Those in the Global South were generally more supportive of climate intervention technologies; however, they also expressed more concern about these technologies undermining mitigation efforts than respondents from the Global North (26) • An online survey of individuals from 30 countries with at least 1,000 participants from each country. • The study notes that those in the Global South were generally more supportive of climate intervention technologies, but they also expressed more concern about these technologies undermining mitigation efforts than respondents from the Global North. • Ecosystem-based approaches were preferred over solar radiation modification, which received the lowest support. • Demographics in the Global South were generally younger and expressed higher climate change concern, in part because they reported more personal experience with natural disasters. • Both regions preferred supportive national-level policies over restrictive approaches, but the Global South showed greater support for international oversight and governance.	High	Publication date: October 2024 Jurisdiction studied: Global Methods used: Online survey	• Place of residence
• Methods of solar radiation modification ○ Stratospheric aerosol injections ○ Marine cloud brightening ○ Space mirrors • Views and perspectives	Tweets on solar radiation modification are generally negative and were found to be associated with negative emotions and often included conspiracy-related keywords (27) • The study examined 1.5 million tweets covering greenhouse gas removal and solar radiation modification technologies between 2006 and 2021. • The data set shows greater awareness and attention to greenhouse gas removal technologies and compared to solar radiation modification, with a significant increase in attention to greenhouse gas removal recently. • General geoengineering tweets were found to have high shares of negative sentiment and low shares of positive sentiment, but the share of negative greenhouse gas removal tweets is much lower, particularly compared to those that specifically mention solar radiation modification. • Stratospheric aerosol injection and ocean fertilization are the only technologies that feature a higher share of negative sentiments than general tweets. • Specific emotions, namely disgust, dominates in both general geoengineering and solar radiation modification followed by fear and anger. • High shares of general geoengineering and solar radiation modification tweets contain conspiracy-related keywords, namely with prominent chemtrails theories.	High	Publication date: December 2023 Jurisdiction studied: Global Methods used: Social media analysis	• None reported

Appendix 4: Single studies on public opinion and behavioural effects of solar radiation modification by country

Jurisdiction	Dimension addressed	Hyperlinked URL	Deliberative method
Australia	Views and experiences	Storylines of geoengineering in the Australian media: An analysis of online coverage 2006–2018 (2021)	Newspaper analysis
China	Views and experiences	Chinese public's perceptions and understanding of the potential roles of solar climate engineering for reducing climate change risks (2024)	Online survey
Finland	Views and experiences	'Bog here, marshland there': Tensions in co-producing scientific knowledge on solar geoengineering in the Arctic (2022)	Focus groups
		Perspectives on solar geoengineering from Finnish Lapland: Local insights on the global imaginary of Arctic geoengineering (2020)	Semi-structured interviews
Germany	Views and experiences	Effects of opinion statements on laypeople's acceptance of a climate engineering technology (2021)	Online survey and citizen jury
		Psychological factors influencing laypersons' acceptance of climate engineering, climate change mitigation and business as usual scenarios (2020)	Online survey
		Public perceptions of climate engineering: Laypersons' acceptance at different levels of knowledge and intensities of deliberation (2019)	Online survey and citizen jury
		The role of affect in attitude formation toward new technologies: The case of stratospheric aerosol injection (2017)	Online survey
		Knowledge about aerosol injection does not reduce individual mitigation efforts (2016)	Online survey
		Public perception of climate engineering and carbon capture and storage in Germany: Survey evidence (2016)	Online survey
		Exploring public perceptions of stratospheric sulfate injection (2015)	Online survey
		Laypeople's risky decisions in the climate change context: Climate engineering as a risk-defusing strategy? (2014)	Online survey
		Laypeople's risky decisions in the climate change context: Climate engineering as a risk-defusing strategy? (2014)	Online survey
Japan	Views and experiences	Ambivalent climate of opinions: Tensions and dilemmas in understanding geoengineering experimentation (2015)	Focus groups
New Zealand	Views and experiences	A quantitative evaluation of the public response to climate engineering (2014)	Interviews
Portugal	Views and experiences	'It's just a Band-Aid!': Public engagement with geoengineering and the politics of the climate crisis (2022)	Focus groups
Switzerland	Methods of solar radiation modification	Support for the deployment of climate engineering: A comparison of ten different technologies (2020)	Online survey
	Views and experiences	Public perception of solar radiation management: The impact of information and evoked affect (2017)	Online survey
United Kingdom	Governance	Public perceptions of geoengineering research governance: An experimental deliberative approach (2017)	Mixed methods
		Living the global social experiment: An analysis of public discourse on solar radiation management and its implications for governance (2013)	Focus groups
	Views an experiences	Geoengineering, moral hazard, and trust in climate science: Evidence from a survey experiment in Britain (2016)	Online experiment

Jurisdiction	Dimension addressed	Hyperlinked URL	Deliberative method
		Exploring early public responses to geoengineering (2012)	Mixed methods
	Ethics	Geoengineering, climate change scepticism and the ‘moral hazard’ argument: An experimental study of U.K. public perceptions (2014)	Online experiment
United States	Views and experiences	Presenting balance geoengineering information has little effect on mitigation engagement (2024)	Social media responses
		Moral hazards and solar radiation management: Evidence from a large-scale online experiment (2024)	Online experiment
		Assessing solar geoengineering research funders: Insights from two U.S. public deliberations (2020)	Public forums
		Fast, cheap and imperfect? US public opinion about solar geoengineering (2019)	Online survey
Multi-jurisdiction – Mexico, U.K., U.S.	Governance	Like diamonds in the sky? Public perceptions, governance, and information framing of solar geoengineering activities in Mexico, the United Kingdom, and the United States (2023)	Online survey
Multi jurisdiction – Australia, India, Japan, Philippines	Views and experiences	Public attitude toward solar radiation modification: Results of a two-scenario online survey on perception in four Asia–Pacific countries (2024)	Online survey
Multi-jurisdiction – U.S., Singapore	Views and experiences	Exposure to climate change information predicts public support for solar geoengineering in Singapore and the United States (2023)	Online experiment
Multi-jurisdiction – Pakistan, Nigeria, Kenya	Views and experiences	Exploring the academic perceptions of climate engineering in developing countries (2023)	Online survey
Multi-jurisdiction – India, Sweden, U.S., U.K.	Views and experiences	Conspiracy spillovers and geoengineering (2023)	Social media analysis
Multi-jurisdiction – Australia, China, India, Japan, the Philippines, South Korea	Views and experiences	The North-South divide on public perceptions of stratospheric aerosol geoengineering? A survey in six Asia-Pacific countries (2020)	Online survey
Multi-jurisdiction – Kenya, Soloman Islands, U.S.	Views and experiences	Perceptions of climate engineering in the South Pacific, Sub-Saharan Africa, and North American Arctic (2018)	In-depth interviews
Multi-jurisdiction – Canada, China, Germany, Switzerland, U.K., the U.S.	Views and experiences	Beliefs and values explain international differences in perception of solar radiation management: Insights from a cross-country survey (2017)	Online survey
Multi-jurisdiction – Japan, New Zealand, U.S., Sweden	Views and experiences	Making sense of climate engineering: A focus group study of lay publics in four countries (2017)	Focus groups
Multi-jurisdiction – Canada, U.K., U.S.	Views and experiences	Public understanding of solar radiation management (2011)	Online survey

Appendix 5: Single studies on expert roundtables or expert focus groups on solar radiation modification

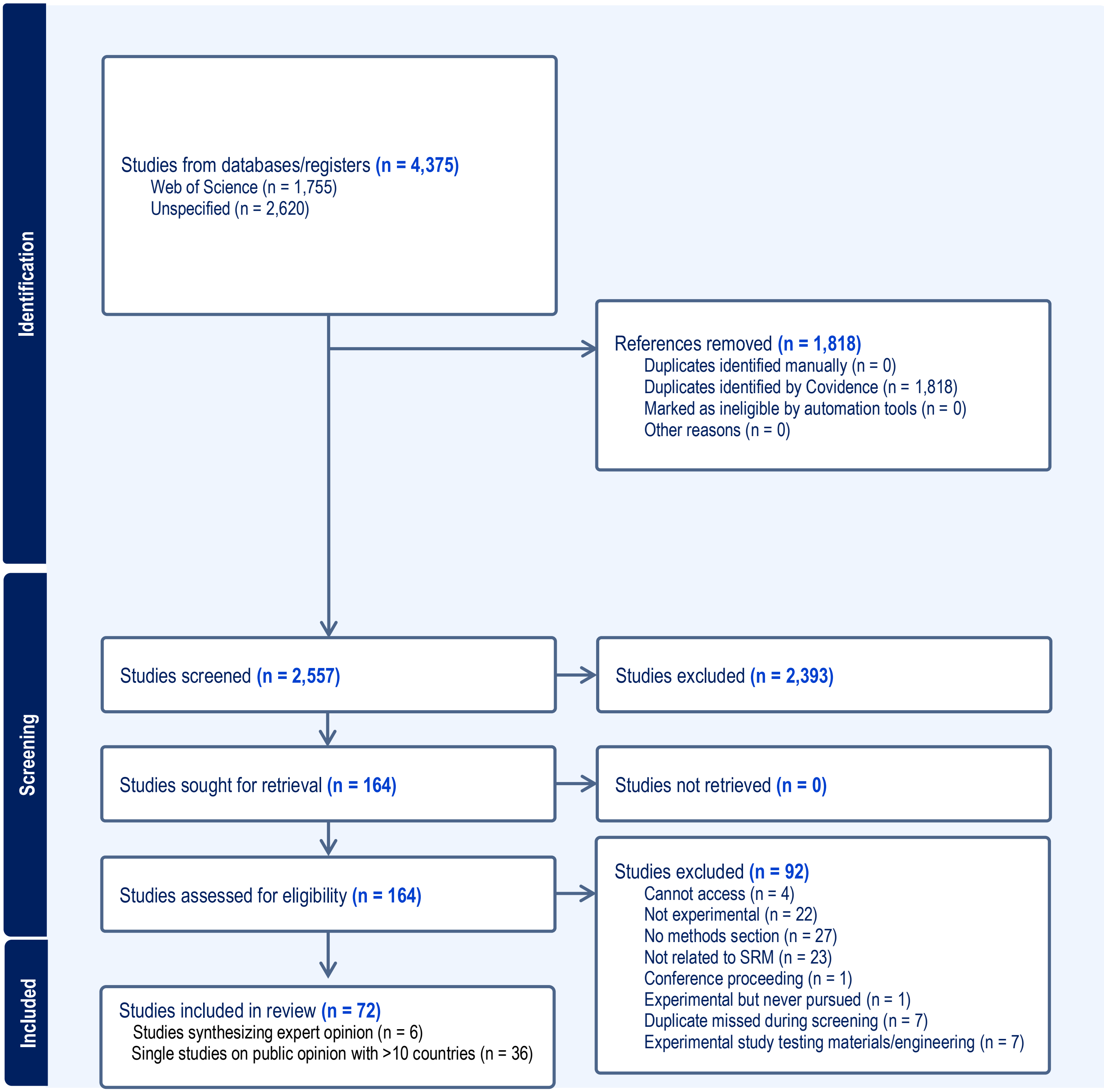
Deliberative method	Description of experts	Hyperlinked title

Roundtable	• 45 mid-career environmental leaders	Engaging the Global South on climate engineering research
In-depth interviews	• 125 experts closely associated with negative emissions and/or solar geoengineering research, development, and commercialization	Between the sun and us: Expert perception on the innovation, policy and deep uncertainties of space-based solar geoengineering
	• Experts that have published high-quality peer-reviewed research papers, published patents, or held intellectual property within the past 10 years on carbon removal and solar geoengineering	Beyond climate stabilization: Exploring the perceived sociotechnical co-impacts of carbon removal and solar geoengineering
Multi-criteria options mapping	• 12 experts in fields related to geoengineering	'Opening up' geoengineering appraisal: Multi-criteria mapping of options for tackling climate change
Survey	• 125 experts with peer-reviewed research papers, published patents, or had intellectual property from the past 10 years on negative emissions or solar radiation modification	Determining our climate policy future: Expert opinions about negative emissions and solar radiation management pathways
	• 17 climate and energy experts from Southeast Asia	Southeast Asian expert perceptions of solar radiation management techniques and carbon dioxide removal approaches: Caution, ambivalence, risk precaution, and research direction

Appendix 6: Evidence syntheses that did not provide details on how literature was identified or included

Dimension addressed	Hyperlinked title
General overview	Reflecting upon 10 years of geoengineering research: Introduction to the Crutzen + 10 special issue (2017)
	Strategies for mitigation of climate change: A review (2020)
	An overview of the earth system science of solar geoengineering (2016)
	Ecosystem impacts of geoengineering: A review for developing a science plan (2012)
	Climate change: Climate engineering through stratospheric aerosol injection (2012)
	Monitoring of geoengineering effects and their natural an anthropogenic analogues (2011)
	Climate engineering: A critical review of approaches to modify the global energy balance (2009)
Governance	Improving risk governance strategies via learning: A comparative analysis of solar radiation modification and gene drives (2024)
	The politics and governance of research into solar geoengineering (2021)
	Solar geoengineering to reduce climate change: A review of governance proposals (2019)
	The international politics of climate engineering: A review and prospectus for international relations (2015)
Harms and benefits	Potential effects of climate change and solar radiation modification on renewable energy resources (2024)
	The potential environmental and climate impacts of stratospheric aerosol injection: A review (2024)
	Reckless or righteous? Reviewing the sociotechnical benefits and risks of climate change geoengineering (2021)
	The effects of solar radiation management on the carbon cycle (2018)
Views and experiences	What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for future research
Engineering of solar radiation management approaches	An update on engineering issues concerning stratospheric aerosol injection for geoengineering (2020)
	Sub-micrometer salt aerosol production: Marine cloud brightening (2013)

Appendix 7: PRISMA diagram



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