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Implications of geoengineering for developing countries

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Key messages

- Climate geoengineering – deliberate, large-scale intervention in the Earth's atmosphere to mitigate climate change – has gained increasing attention. Two main kinds of intervention have been proposed: carbon dioxide removal (CDR), which reduces atmospheric CO_2 levels; and solar radiation management (SRM), which increases the Earth's reflectivity.
- As climate-related weather extremes continue and if progress towards decarbonisation proceeds at its current pace, policy-makers may begin to consider geoengineering, particularly SRM, as an emergency 'plan B' to reduce adverse effects of climate change.
- The cross-border nature of geoengineering points to the need to engage developing countries in discussions about research, governance and potential deployment, as well as the need for a new approach for decision-making about geoengineering.
- So far engagement by developing countries in discussion about geoengineering has been limited. More support is needed to enable developing countries to assess the costs and benefits of geoengineering, including the potential for unintended consequences.
- Longer term, any geoengineering research and governance arrangements that are agreed and put into practice may have important implications for climate governance and broader interventions to manage risks associated with other planetary boundaries.

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1. Introduction

The parties to the Paris Agreement on climate Change agreed to limit 'the increase in the global average temperature to well below 2°C above pre-industrial levels [while] pursuing efforts to limit the temperature increase to 1.5°C.'[1] However, the climate pledges, or Nationally Determined Contributions (NDCs), underpinning the Paris Agreement are not yet adequate to fulfil its goals. As UNEP (2016) noted, NDCs 'represent a first start to initiate the required transition, but are far from being consistent with the agreed upon long-term temperature goals'.

The Paris Agreement is also closely linked to the Sustainable Development Goals adopted by the United Nations in 2015. Taking urgent action to combat climate change is Goal 13. This is closely linked with policies and actions to achieve other Goals and driven by the need to avoid reversing development progress, which could occur as a result of temperature increases and other climate-related risks (see, for example, Granoff et al., 2015).

Recent extreme weather events highlight the risks and potential negative impacts associated with climate change (McKibben, 2017; McMahon, 2017; Santini, 2017). Developing countries, which are least responsible for historical greenhouse gas (GHG) emissions, will likely bear the brunt of the economic impacts of climate-related shocks, as well as of other adverse effects that are likely to intensify as a result of climate change (IPCC, 2012). Developing countries are also least able to recover from such shocks and to adapt to a rapidly changing climate (Fuhr, 2016b).

Geoengineering or climate engineering[2] – the deliberate large-scale alteration of the Earth's environment to counteract climate change[3] through GHG removal or altering the Earth's reflectivity (or albedo effect) – is receiving increasing attention from policy-makers and researchers as a potential means to mitigate the impacts of climate change. Authoritative organisations like the UK's Royal Society and the Intergovernmental Panel on Climate Change (IPCC) have published significant work on geoengineering (see, for example, Royal Society, 2009; Shepherd and Parker, 2016; and IPCC, 2011, 2012).

Views on whether geoengineering is needed are divided. Proponents highlight that most IPCC scenarios that yield a 1.5°C future rely not only on ambitious global mitigation but also on the removal and storage or sequestration of large amounts of GHGs. Geoengineering opponents note that mitigation efforts alone could stabilise the climate, and view geoengineering as a distraction from a commitment to rapid decarbonisation. Geoengineering research, however, continues to gain momentum and attract funding from governments and foundations (see Appendix 1). Harvard University recently initiated a Solar Geoengineering Research Program,[4] Carnegie Council launched a Climate Geoengineering Governance Initiative (C2G2),[5] and universities such as Stanford and Oxford have active geoengineering research programmes.[6] As a sign of this momentum, the second international Climate Engineering Conference took place in Berlin in October 2017.

Except for efforts such as the Solar Radiation Management Governance Initiative (SRMGI),[7] which is relatively small, research on the feasibility of geoengineering is undertaken mainly by institutions in industrialised countries. Experts from member countries of the Organisation for Economic Co-operation and Development (OECD) dominate debate about the effectiveness and potential consequences of geoengineering interventions. Developing country participation in geoengineering research and policy discussion has been mainly limited to large emerging economies with strong science and technology capabilities. Yet the potential impacts of geoengineering are global in nature, affecting all countries, and will vary across different regions. This suggests a need for inclusive debate and decision-making about geoengineering, as well as for more significant support for research into the potential impacts of geoengineering on developing countries.

This working paper focuses on geoengineering as a potentially significant climate and development policy issue

1 http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

2 This paper uses geoengineering as shorthand for climate engineering; however the terms are interchangeable.

3 This definition is adapted from Royal Society (2009) and Lempert and Prosnitz (2011).

4 https://geoengineering.environment.harvard.edu

5 https://www.c2g2.net

6 http://gcep.stanford.edu/research/geoengineering.html, http://www.geoengineering.ox.ac.uk

7 See SRMGI (http://www.srmgi.org/).

for developing countries. It raises questions that developing country policy-makers, who may not yet be engaged with climate geoengineering, may soon need to consider. In view of current trends, this brief also suggests areas for future policy research that would be required to ensure inclusive governance of climate geoengineering research and potential interventions.[8]

8 Potential resources for future research have been identified on a preliminary basis in Appendix 1.

2. Types of intervention and potential benefits

Geoengineering can be considered as two types of intervention: carbon dioxide removal (CDR), which addresses one of the main causes of climate change by extracting carbon from the atmosphere; and solar radiation management (SRM), which aims to reduce global warming by preventing sunlight from reaching the Earth.[9] Each type is described in further detail below.

2.1. Carbon dioxide removal

CDR – including 'negative emissions technologies' such as afforestation, bioenergy with carbon capture and storage (BECCS), carbon sequestration by algae and biochar, and direct air capture – aims to remove CO_2 from the atmosphere, thereby reducing the atmospheric concentrations of CO_2 (see Swart and Marinova, 2010, for an overview). If effective, CDR would gradually limit the increase in average temperatures. CDR methods vary depending on how CO_2 is absorbed from the atmosphere and where it is ultimately stored. Both ocean-based and land-based interventions can have impacts that cross national borders (even though they may be located within a specific territory), especially when projects are considered cumulatively. Appendix 2 presents an overview of some commonly proposed CDR interventions.

To have a significant effect on GHG concentrations – and, as a result, average global temperatures – the scale of interventions would need to be large. According to the Royal Society (2009):

> *[Effective CDR would] require the creation of an industry that moves material on a scale as large as (if not larger than) that of current fossil fuel extraction, with the risk of substantial local environmental degradation and significant energy requirements. Enhanced weathering might [meanwhile] require mining on a scale larger than the largest current mineral extraction industry, and biologically based methods might require land at a scale similar to that used by current agriculture worldwide.*

Such a scale could then create competition with other resources, as Craik and Burns (2016) note: 'Delivery of a relatively modest three gigatons of carbon dioxide equivalent negative emissions annually could require a land area [equal to] 7 to 25 percent of agricultural land and 25 to 46 percent of arable and permanent crop area.'

2.2. Solar radiation management

SRM, or 'albedo modification', aims to reduce incoming solar radiation, which warms the planet, and includes interventions such as the injection of aerosols into the stratosphere, launching reflectors in space, modifying clouds by injecting sea water, and increasing the reflectivity of the Earth's surface (see Swart and Marinova, 2010, for a summary).

By contrast to CDR, SRM technologies in theory provide a near-immediate effect on global temperatures. They are therefore sometimes described as a potential 'stop-gap measure' or a last-resort tool to 'buy time' (Barrett, 2008; Victor et al., 2009; Keith, 2000). SRM interventions, such as the injection of stratospheric aerosols, are considered relatively inexpensive in operational terms compared to CDR. However, SRM only treats the symptoms of climate change by reducing radiative forcing, not the main cause (i.e., elevated GHG concentrations).

SRM began to gain research attention after Nobel laureate Paul Crutzen published an essay on geoengineering, thereby opening the field for policy consideration (Crutzen, 2006). A wide range of SRM methods have since been proposed, modelled and analysed on a theoretical basis. The range of proposed methods varies according to whether they reflect or deflect incoming solar radiation and whether the intervention is in space, the atmosphere, or at the Earth's surface.

One category of potential intervention involves placing reflectors in space, either in orbit close to the Earth or at the mid-point between the gravitational pull of the Earth and that of the Sun. Even if technically feasible (Royal Society, 2009), the logistical and governance challenges associated with such an endeavour mean we have neither

9 Issues regarding whether a proposed technology or methodology can be classed as geoengineering depend on a range of factors, including whether the technology in question is sufficiently large scale, whether its (primary) aim is to modify the climate and at what scale, typically blurring the line between mitigation, geoengineering, and unrelated processes that affect the climate indirectly. Boucher et al. (2014) note that this is such an issue that it would be better to divide geoengineering into five types of intervention overall; however, this approach does not seem to have been widely adopted.

practical experience nor a plan for it, and it is not widely discussed today.

A second category of SRM involves injection of aerosol particles into the upper atmosphere to directly reflect radiation to mimic the effects observed of aerosols caused by volcanic eruptions. Such particles tend to remain in the atmosphere for an extended period and could lead to wide-ranging adverse impacts, such as potential changes in rainfall patterns across regions. Although effects of volcanic eruptions have been well studied, and are in some ways comparable to stratospheric aerosol injection, substantial uncertainties remain, not least because many aspects of natural, sporadic aerosol injection have little in common with the potential for continual, managed injection of human-made particles.[10]

A third category involves 'cloud whitening' by spraying small particles into the atmosphere to boost clouds' ability to reflect radiation that would otherwise be absorbed by water or land. This involves using cloud-condensation nuclei – microscopic particles needed for cloud formation – to increase the number of small droplets, in order to boost the reflectivity of clouds. As with other methods, questions remain unanswered regarding the cumulative impacts of widespread use, including on weather patterns, the physical health of humans and other ecosystem dynamics.

A fourth SRM category involves surface interventions. Land, the built environment, ecosystems and the ocean could be manipulated at the Earth's surface to increase their reflectivity. The scale of surface-based SRM intervention may be large and concentrated (for example, covering significant areas of equatorial deserts with special reflective materials) or relatively small and diffuse (for example, painting roofs white), though for small-scale interventions to have a material effect, many of such interventions would be required.

Different SRM interventions are illustrated in Appendix 3.

2.3. Potential benefits

In theory, geoengineering offers the potential to counteract or limit the negative effects of anthropogenic GHG emissions and/or their associated climate impacts. Both CDR and SRM could theoretically be applied to help lower global temperatures, both during the transition to net-zero emissions and later, if emissions trajectories do not decline enough.

The complexity of and uncertainty within global climate models mean the precise impact of SRM interventions on limiting global warming is less clear. Because some SRM options offer the potential to be targeted, they could help counteract specific climate change-related feedback mechanisms (for example, using cloud whitening or seeding to limit Arctic melting), but unintended consequences are largely unknown and hard to predict. By contrast, CDR may offer a way to compensate for the continuation of some GHG-intensive activities (such as concrete and steel production, or aviation) for which there may be no readily available low-carbon alternative.

10 Researchers at Harvard University have begun a five-year programme on this intervention, because, as two of the project's researchers note, 'It would be reckless to deploy solar geoengineering based on today's limited research' (Keith and Wagner, 2016).

3. Risks and uncertainties

The immediate risks associated with geoengineering depend on the mode of operation, scale, period of the project, and location, among many other factors. The impacts of geoengineering options also involve significant uncertainties, particularly with regard to unintended consequences, potentially at a similar scale to the intervention itself (see Box 1 and Appendix 4). The full economic impact of geoengineering interventions includes indirect or external costs and benefits, which are not presently known.

The risks and uncertainties associated with SRM are significant. While the primary, direct, averaged impacts of SRM may be estimated relatively accurately at a theoretical level, substantial uncertainties exist with regard to regional secondary and non-radiative effects, including effects, for example, on monsoon patterns (Hegerl and Soloman, 2009).

Potential downsides of SRM include changes in regional weather patterns that could lead to droughts in Africa and Asia, damage to the ozone layer, continued ocean acidification, impacts on natural ecosystems and agricultural crops, impacts on tropospheric chemistry, diminished radiation for solar power, and the risk of human error, in addition to other factors detailed below (Robock 2008, 2014a, 2014b; Robock et al., 2010; ETC Group, 2017a). Uncertainties associated with the potential impacts of SRM reflect limitations in our understanding of global climate dynamics, including the formation and behaviour of clouds (Royal Society, 2009) and how the climate interacts with other natural systems (Robock, 2008).

For proponents of geoengineering research, these uncertainties are one main reasons to conduct research; in their view, options should not be dismissed until empirical data on wider impacts are available (see, for example, Horton et al., 2016). However, as Russell et al. (2012) note, reducing uncertainty will be difficult because physical differences between potential interventions mean it is difficult to generalise about the impacts of a specific intervention:

> *[T]he interconnectedness of many ecosystem processes across a wide range of spatial and temporal scales leads to systems of such complexity, that outcomes are difficult to predict as the systems move outside any previously observed states.*

The main justification for geoengineering research is to have some way to avoid runaway climate change, beyond transitioning from technologies that emit GHGs, and by uncertainty about the range of possible impacts of geoengineering could have on the Earth's systems. However, even if research proceeds, one of the key challenges will be the scale of experimentation needed to produce meaningful results. Robock et al. (2010) argue that 'geoengineering cannot be tested without full-scale implementation'.

Decisions about geoengineering should take its impacts into account; these effects are better understood for CDR than they are for SRM; see, for example, Burns and Nicholson (2017) and Williamson (2016). A recent report by the secretariat of the Convention on Biological Diversity (Williamson and Bodle, 2016) provides a detailed breakdown of the impacts of each of the major geoengineering techniques, with a focus on their impact on biodiversity. Such impacts may vary in their location, time and manifestation; for example, stratospheric aerosols injected in the northern hemisphere could contribute to droughts in the Sahel, while if they were released in the southern hemisphere they could 'green' the region (Haywood et al., 2013). Besides the expected consequences, any geoengineering option could create unintended impacts, both environmental and non-environmental (Liu and Chen, 2015). It is unclear how such impacts might be factored into decision-making.

In addition, some geoengineering interventions may be best or only suited to specific locations, potentially setting up uneven impacts and benefits, as well as distributional and equity issues. For example, SRM may be most effective closer to the equator.

The potential for these largely non-climate impacts led the Convention on Biological Diversity to oppose field-testing of geoengineering in 2010, which has constituted a *de facto* moratorium also on deployment (CBD, 2010). In December 2016, the Convention reaffirmed its stance against geoengineering:

> *until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting (Decision X/33, paragraph 8, subparagraph (w)).*[11]

The potential moral hazard involved in geoengineering represents a major reason not to pursue any such

11 For more detail on this decision, taken at COP10, see the full text of decision X/33. See also decision XI/20. Both are available at https://www.cbd.int/decision/cop/?id=12299.

interventions, particularly SRM. As Heinrich Böll Foundation observers note, '[g]eoengineering functions as the "perfect excuse" for high carbon emitters to avoid real GHG reductions' (ETC Group, 2016).[12] Olson (2011) explains: 'The belief that an easy technological fix for global warming is available could undermine our political and social resolve to deal with the underlying cause of the problem by reducing green-house gas emissions'. This has already begun to occur with a number of groups opposed to mitigation options adopting pro-geoengineering stances. Lin (2013) states that it is 'likely that geoengineering efforts will undermine mainstream strategies to combat climate change'.

Another concern is the so-called 'termination effect' (Armeni and Redgwell, 2015). If we rely on CDR to limit GHG emissions and meet our carbon budget, or SRM to limit temperature increases, what happens if these interventions end? Just as CDR and SMR are, respectively, slow and fast to have an impact on global warming, the impact of turning off these technologies would likely be different. Stopping CDR would lead to a net increase in GHG emissions because emissions would stop being removed from the atmosphere (either directly or indirectly).[13] Unmanaged, sudden termination of SMR could lead to rapid warming of the climate, causing a temperature rebound. Such a change could affect tipping points, and ecosystems may be unable to adapt fast enough. Concern about dependence on SRM and shocks that may occur upon discontinuation led the IPCC to note that once SRM starts, it may be impossible to stop without causing widespread harm from climate change effects (IPCC, 2007).

Further, because the impacts of geoengineering cross national borders, the ability to manipulate climate and other natural systems could be misused (see, for example, Robock, 2008; 2015). This could give rise to 'weaponisation' if states were to exercise control over the weather, leading to natural disasters or disruptions to crop production in other nations (Radford, 2013; Fuhr, 2016a).[14] Although 85 countries, including the US, have signed the United Nations Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), it is not clear whether the Convention would in fact prevent such a possibility from occurring (Armeni and Redgwell, 2015).

12 For more on the moral hazard dimensions of deterring mitigation, see McLaren (2016).

13 This could be particularly important if we 'overshoot' our emissions budget and then rely on net negative emissions to hold us to a 2°C carbon budget

14 Depending on the technology, it is also possible that geoengineering facilities themselves would require military security.

4. Relevance to developing countries

The potential impacts of geoengineering are relevant to all countries and regions.[15] Immediate concerns for developing countries may involve the potential direct and indirect physical impacts of geoengineering, both intended and unintended; and the degree to which developing countries are engaged as partners in decision-making on research, development, deployment and measurement of geoengineering interventions, as well as the response to any unforeseen impacts. Given the potential military applications of geoengineering, implications for peace and security should also be considered.

For some developing countries, the unintended consequences of geoengineering could be particularly harmful and inequitable. As Olson (2011) points out:

> *populations living at the edge of subsistence – those with the least capacity to adapt to the impacts of climate change and almost no voice in international deliberations – are precisely the populations that will be most vulnerable to any negative side effects that geoengineering experiments might have.*

Box 1 provides an overview of the potential impacts of geoengineering on developing countries, focusing on Asia.

Moreover, formal governance and associated international policy and institutions for both the development and the deployment of geoengineering remain inchoate, putting developing countries at a significant disadvantage in terms of engagement in policy-making. Most research in this field has so far been carried out in developed countries (Laplaza, 2017; McLaren, 2017), with limited representation from developing countries.[16]

Emerging markets and developing countries may respond in different ways to the potential of geoengineering. Their positions may be informed more by geopolitical perspectives and the impacts they expect climate change to have than by economic comparisons between theoretically modelled interventions. Individual countries will have distinct priorities regarding and views

Box 1. Potential impacts on and representation of developing countries

'The interconnected monsoons of South, East, and Southeast Asia together shape the climates of 20 countries representing approximately half of the global population. Natural analogues and climate model simulations suggest that climate engineering, specifically proposed solar radiation management (SRM) technologies, could severely influence monsoonal precipitation. [...]

'The monsoonal rainfalls' intimate links to biophysical, economic, public health, and agricultural systems underscore the scope and scale of climate engineering's potential implications for the world's most climate vulnerable populations. The simultaneous potential to offset adverse impacts of climate change and to severely disrupt hydrological cycles casts these technologies as both cornucopian and catastrophic. As such, the rhetorical appeals of climate engineering research proponents and opponents alike invoke the effects of theoretical monsoon manipulation on highly vulnerable populations. Notably, however, these appeals underscore a major shortcoming of climate engineering research and policy discourse: the voices of these populations are glaringly absent. […]

'Thus far, developing countries have largely been absent from climate engineering discussions. […] Even as the academic research communities in developed countries recognize the need to engage broader stakeholders such as public authorities, policy communities, and lay citizens, public engagement has yet to meaningfully extend out of the Global North. The meagre engagement with developing countries has been limited to scientists and other technically-literate experts.'

Source: Laplaza (2017).

15 The Action Group on Erosion, Technologies and Concentration (ETC Group) has produced reports of simulations of the regional implications of geoengineering. See ETC Group (2014a, 2014b and 2014c).

16 In addition, only 1 of the 33 speakers at the recent, prestigious geoengineering conference was not from a European or US institution, and even that speaker was a British expatriate based in China (https://www.grc.org/climate-engineering-conference/2017/).

of how, or indeed whether, to manage natural systems that may be formed as much by history and culture as by geographic location and weather patterns.

Countries' scientific and technological capabilities will determine their ability to engage in discussions on geoengineering research, as well as their technical capacity to undertake geoengineering research or interventions. Consequently, support for geoengineering, and the capacity, expertise and will to engage in discussion about its potential risks and benefits, will vary among countries (Williamson and Bodle, 2016). For example, the strategic interests of China and India, as large economies vulnerable to a range of climate impacts and with enough resources to manage a geoengineering intervention themselves, may be quite different from those of Burkina Faso or Myanmar, which may currently be less able or willing to engage with the relevant issues. Moreover, such interests may be conflicting or even directly opposed as Laplaza (2017) notes in the context of the interdependence between the monsoons in India and China:

> *If one state wishes to augment the intensity of its monsoon to boost agricultural productivity (as China might) or mitigate the threat of increasingly frequent and intense flooding events (as India might), it could conceivably do so at the expense of the other.*

In view of these risks, some developing countries have already expressed their support for the 'precautionary principle'[17] by calling for a moratorium on field geoengineering experiments during the opening week of the 10th Conferences of Parties (COP 10) to the UN Convention on Biological Diversity (Leahy, 2010). Still, both India and China are developing national geoengineering research programmes (Bala and Gupta, 2017; Liu and Chen, 2015).

4.1. Resource and capacity needs

The ability to engage in and critically assess geoengineering research or potential deployment, even theoretically, would require significant financial resources and technical capacity, including with regard to the capacity and/or technical expertise needed to monitor, measure, and attribute impacts caused by geoengineering interventions. Issues here are clearly linked to a country's existing resources, including whether existing efforts (e.g., regarding weather monitoring) can be repurposed to provide geoengineering-related information.

4.2. Information and technical requirements

Should any geoengineering interventions be undertaken, including research, a country's ability to understand (or detect) any impacts will depend on the pre-existence of baseline atmospheric measurements and the reliability of any third-party data used for verification. Moreover, actually carrying out such measurements requires significant levels of technological knowledge and the ability to access and manage specialized expertise. Developing countries need to be able to communicate implications of geoengineering, which in turn means being able to produce information and decision-making tools available in an accessible format to support policy-makers facing difficult, uncertain, and potentially impactful choices.[18]

4.3. Modelling of potential impacts

A country's ability to model the impacts of changes in weather patterns caused by geoengineering interventions, and the resulting effects on its population, resources, and wider economy will affect the robustness of evidence-based policy. This is likely to be particularly important in countries where rain-fed agriculture represents a significant portion of the economy. Similarly, from a security perspective, it is important to be able to analyse the potential impacts from geoengineering interventions undertaken by another country, and whether countries are able to prevent others from undertaking geoengineering interventions outside of their own borders that may nonetheless have domestic effects.

4.4. Decision-making tools

The broad range of potential implications mean that countries may need to develop their existing decision-making tools. For example, countries may need to assess whether the future potential of geoengineering interventions will lead to domestic and/or international delays in climate mitigation actions, thus raising the potential long-term costs of climate change damage (moral hazard). Or, alternatively to evaluate whether geoengineering developments (or their potential application) will affect investment in adaptation measures.

17 The precautionary principle is the notion that risk should be avoided, even when its likelihood seems remote. It has long been enshrined in environmental and sustainable development (see O'Riordan and Cameron, 2013). For example, in 1992, Principle 15 of the Rio Declaration on Environment and Development was agreed as: 'In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation' (Read and O'Riordan, 2017).

18 For example, an overshoot in temperature in the absence of stratospheric SRM (for technical, operational and/or political reasons) and potential deployment of stratospheric SRM without fully knowing its likely impacts.

5. Governance implications

Debate is ongoing as to whether geoengineering will be necessary, and whether research into potential interventions should be conducted.[19] However, pressure to move geoengineering from research to practice may increase if climate conditions worsen, as projected, given the current level of ambition, and if political commitment to rapid decarbonisation does not strengthen in line with the Paris Agreement goals[20]. Next year's IPCC report, which will focus on a 1.5°C future, may further draw attention to geoengineering as a necessary climate policy option if the Paris Agreement's objectives are to be fulfilled. So far, attention has focused on the governance of geoengineering research rather than on deployment, giving rise even at this smaller scale to a wide range of questions, including how research can be self-regulated. Box 2 summarises geoengineering researchers' approaches to adopting principles for self-regulation.

Given the slow pace of decarbonisation and the limited timeframe for meaningful action (see Figueres et al., 2017), interest in 'emergency measures', including geoengineering, as a 'plan B' may build (see Swart and Marinova, 2010). Geoengineering may capture policy-makers' attention as a potential 'back-up' plan if rapid decarbonisation proves impractical. Interest in or pressure to undertake geoengineering could come from developed countries that foresee a risk of radical socio-economic change in the absence of intervention, countries suffering from climate-related weather disasters or facing existential questions because of sea-level rise, or developing countries that have significant experience with weather manipulation, such as China (Liu and Chen, 2015).[21] If climate conditions continue to deteriorate, policy-makers may need to form views on how geoengineering should be governed in practice. Governance issues can be broadly framed in terms of their international and domestic aspects.

Box 2. Self-regulatory principles

To calm fears of geoengineering proponents 'going rogue' (Olson, 2011), researchers adopted plans to self-regulate. The consensus formed at the Asilomar Conference in 2010 followed the approach taken by genetics researchers in the same location in the 1970s and drew on the previously suggested Oxford Principles (see below). Recently the Geoengineering Research Governance Project released a code of conduct for geoengineering research (Hubert, 2017).

Asilomar Principles (2010)

1. Promoting collective benefit
2. Establishing responsibility and liability
3. Open and cooperative research
4. Iterative evaluation and assessment
5. Public involvement and consent

Oxford Principles (2009)

1. Geoengineering to be regulated as a public good
2. Public participation in geoengineering decision-making
3. Disclosure of geoengineering research and open publication of results
4. Independent assessment of impacts
5. Governance before deployment

Source: http://blogs.nature.com/news/2010/11/asilomar_geoengineering_confer.html and http://www.geoengineering.ox.ac.uk/oxford-principles/principles/

5.1. International aspects of governance

If geoengineering enters the climate policy mainstream, important governance questions will arise for both developed and developing countries. Unless representation of all countries can be developed to legitimise decisions, some countries could justify their geoengineering interventions in terms of preventing damage by climate-related extreme weather, even if such intervention runs against the wishes of other countries. This would require a multilateral approach to governance, though it is not clear that the United Nations Framework Convention on Climate Change (UNFCCC) would present an effective model for this approach, particularly if countries were to view the timeframe for decision-making as limited.

19 See Armeni and Redgwell (2015) pp. 9–10 for an example of the varying viewpoints on the need for geoengineering. For an overview of the associated ethical implications, see https://www.yaleclimateconnections.org/2012/12/the-ethics-of-geoengineering-part-2/.

20 A recent report showed that two-thirds of major emitting countries will not meet their NDCs with current policies. (Kuramochi et al., 2017)

21 For examples of this, see https://en.wikipedia.org/wiki/Beijing_Weather_Modification_Office, https://www.reuters.com/article/us-china-weather-idUSKCN0ZU0CE and http://fortune.com/2017/01/24/china-government-artificial-rain-program/.

Governance could be even more exclusive and problematic in the event of an 'emergency' intervention by a group or body, such as the UN Security Council, which may not have the technical competence or expertise, breadth of representation, or mandate to take potentially irreversible planetary-level decisions. As noted above, these issues may be particularly acute for developing countries, which so far have had limited representation in geoengineering research and policy discussions.

Even before considering specific options for the governance of geoengineering, Hamilton (2013) raises a number of questions in relation to SRM that could apply to other types of geoengineering intervention:

> *Those who defend solar radiation management research as a form of preparation for a crisis have yet to provide answers to the following questions: What are the criteria for a climate emergency requiring rapid intervention? Who would determine that an emergency exists? Who would authorize the emergency response, and from where would they derive their legitimacy? Who would decide that the emergency is over?*

These questions remain relevant even without a 'climate emergency' or crisis: Who decides? Under what conditions precisely would intervention be justified? Under what conditions and how would an intervention end?

The adequacy of existing regulations to govern interventions varies according to the type of proposed intervention. Even if geoengineering interventions are undertaken within national boundaries, in aggregate if not individually, they will likely have trans-boundary impacts. It is not clear whether national regulations (for example, for environmental impact assessment) or international conventions and treaties would be adequate. For interventions that themselves cross national boundaries, it seems unlikely that international laws would be adequate, particularly for interventions outside national jurisdictions, such as on the high seas or in the upper atmosphere.

Many governance issues related to geoengineering remain unresolved, both for research and for deployment. The broad range of technical, political and ethical issues involved in research suggests the need to bring together a diverse range of practitioners from different disciplines – from engineers and climate scientists to philosophers and sociologists and ecologists and economists. A review of the legal literature 'emphasizes the unfeasibility, and arguably undesirability, of any kind of one-size-fits-all approach to geoengineering governance' (Armeni and Redgwell, 2015), which adds to the complexity of the challenge ahead and has led opponents of geoengineering to call for a complete ban.[22] As Armeni and Redgwell (2015) observe:

> *the legal and regulatory implications of geoengineering governance are not limited to the intuitive realm of environmental controls. Rather, they are likely to require a much deeper analysis of other areas of international regulation, such as international trade, food security, intellectual property rights, and international security.*

For developing countries, which may bear more of the risks and whose vulnerability may be used as a justification for intervention, how decisions are made, with regard to developing a potential governance framework, is at least as important an aspect of governance. Olson (2011) notes that 'it may well be even more difficult to reach agreement on geoengineering than on emissions reductions', raising the prospect of unilateral intervention:

> *No international institutions or arrangements exist to authorize field tests or deployments or to make decisions about 'where the thermostat should be set'. The results of geoengineering initiatives could be geographically uneven, producing angry losers as well as winners. The north-south divisions so evident at the Copenhagen Summit would almost certainly be intense around geoengineering. Finally, some people believe for religious or philosophical reasons that it is wrong for humans to interfere so fundamentally with the Earth's natural processes.*

Because it remains unclear how decisions involving geoengineering will be made, particularly for developing countries, interested and affected parties, as well as policy-makers, need to begin to engage in dialogue on how, when, and by whose agency geoengineering may develop.

Whether potential interventions are intended to alter the global climate, are 'targeted' to the local climate or have wide-ranging impacts, the governance of geoengineering is highly context-dependent, and current treaties, laws and regulations do not fully cover any proposed geoengineering practices (Armeni and Redgwell, 2015). From a legal perspective, this lack of a general rule in relation to geoengineering means some interventions can use parts of existing regulations[23] while others (like atmospheric or space-based SRM interventions) would require entirely new international agreements (for an overview of treaty options, see Swart and Marinova, 2010).

The precautionary principle, adopted at the Rio Summit in 1992, has provided a general rule for environmental governance and international environmental agreements and, as noted in a detailed review, 'has been included in almost all recent treaties and policy documents relating to the protection and preservation of the environment, and it is widely accepted [as] intrinsic to international

22 The ETC Group (2016) state that: 'Demands for geoengineering experiments, as well as suggestions to consider geoengineering proposals "case-by-case", are slippery slopes. They obscure the core issue: all geoengineering proposals attempt to modify the global climate, and should therefore remain the subject of global UN negotiations. CBD [the Convention on Biological Diversity] must affirm the precautionary approach. Open-air experiments on geoengineering should not be allowed.'

23 For example, the London Convention and Protocol was adopted to prohibit marine geoengineering except for legitimate scientific research, while the 1976 ENMOD Convention could be further adopted, enforced, or updated to prevent weaponisation.

environmental policy' (Stakeholder Forum for a Sustainable Future, 2011, p. 93 and numerous other places). In this dynamic and uncertain context, it is not clear that the existing governance institutions provide a sufficiently robust and comprehensive framework for the issues that will arise in relation to potential geoengineering interventions. On which current institution can developing countries rely to take decisions on SRM interventions with their interests in mind? Developing countries may need to push for either a new UN agency or a new international body, in which their interests are effectively represented, to collect current and future data, manage the implementation of potential interventions, monitor programme activity, and report on both intended and unintended results.

Finally, the fact that potential impacts of conventionally defined geoengineering interventions are wide-ranging means that the scope of 'management' is wider than governance of the climate system (Dalby, 2015; see also Box 1 in Olson, 2011). While the UNFCCC model may be relevant for GHG emissions and climate impacts, it may not be well suited to taking decisions on, or managing, other aspects of geoengineering. Moreover, resolution of governance questions for geoengineering may serve as a template for how to manage other planetary boundaries[24] – the framework for the Earth system that defines a 'safe operating space for humanity' (Steffen et al., 2015; Morton, 2015).

5.2. Domestic aspects of governance

Current practices suggest that countries that seek to undertake geoengineering research or deployment may do so within their domestic boundaries, irrespective of barriers or impediments that may be in place under international law. All countries may wish to consider questions like those posed at a meeting of researchers and policy-makers in India (Bala and Gupta, 2017): 'What should our country's role be in developing a global governance framework for geoengineering?' and 'What should our country's stand be on geoengineering, nationally and internationally?'[25]

To address such questions may require answering more technical questions like: 'What would the effects be on our country?' and in turn, 'What resources do we need to develop to understand the potential impacts of geoengineering on our country?', 'How would we know if our country were being affected by geoengineering?' or 'What could we do if a country was implementing these interventions against our wishes?'[26] These questions do not form an exhaustive list but asking them represents a first step in the engagement process (Olson, 2011).

24 See http://www.stockholmresilience.org/research/planetary-boundaries.html and http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html

25 To be clear, answering these questions should not be interpreted as a passive acknowledgement that geoengineering should go ahead at all.

26 This has been termed the 'free-driver problem'. For more details, see Weitzman (2012).

6. Directions for policy research

Geoengineering has been proposed as a potential technological solution to the divergence between the GHG reductions needed to avoid catastrophic climate change and the emissions trajectories currently forecast. Planet-level interventions have the potential to create significant impacts, both positive and negative. The diverse nature of these impacts means that many aspects of geoengineering present new challenges that cross many disciplines: the effectiveness and feasibility of proposed technologies remains uncertain and important governance issues remain unresolved. Proponents of geoengineering research continue to push for more recognition at an international level. However, many policy-makers have not yet been exposed to or involved in the issues raised by geoengineering.

Given that most work has been carried out in a small group of developed countries, and that policy-makers may need to address this issue in the foreseeable future, it is vital to ensure that developing countries are well prepared to make certain that their interests are taken into consideration in decision-making on geoengineering proposals.

In view of this priority, on the basis of initial research, it will be important to answer the following questions:

1. How do developing country governments, businesses and citizens perceive geoengineering? What is the level of awareness and knowledge about geoengineering and its potential impacts?
2. What is required to enable developing countries to make informed decisions about research into geoengineering or the potential deployment of geoengineering interventions? What do developing countries believe they will need in order to engage in these discussions? How could gaps in knowledge, resources or capacity be filled?
3. How are different developing countries engaging or preparing to engage with international discussions about geoengineering?
4. What support initiatives are there to assist developing countries, how do they interlink and how could they be enhanced?
5. What options and/or strategies are, or may be, available to developing countries to ensure that their voices are heard in international geoengineering dialogue? How could current international and regional structures be used to ensure inclusive decision-making and equitable outcomes for developing countries?

As momentum builds around geoengineering, developing countries should take steps to engage actively in research and policy discussions, to ensure their interests are represented both in the governance structures in which any decisions about geoengineering are taken in the future, and in the decisions themselves. They should be supported to do this. Legitimacy demands that developing countries have a significant and proportional voice in geoengineering decisions, even at the experimental stage, implying that a new approach may be needed for climate decision-making.

Exploration of the full range of governance issues, including research, deployment and monitoring of technologies such as SRM, represents an important potential focal area for future research that, if undertaken in a transparent and inclusive manner, would complement and enhance ongoing initiatives. For example, SRMGI aims to connect developing country actors across society nationally and across borders, C2G2[27] promotes effective governance by shifting the discussion from researchers to society and policy-makers,[28] and the Heinrich Böll Foundation and the ETC Group (2017b) recently proposed a set of requirements for legitimate geoengineering governance.[29]

Existing approaches, such as multilateral agreements (for example, UNFCCC), may be useful, but these are often slow processes and there is no guarantee that agreement will be reached. The forum for these discussions is therefore not obvious, even among candidates such as UNFCCC, the United Nations Educational, Scientific and Cultural Organization (UNESCO), the UN General

27 See https://www.c2g2.net/c2g2-priorities/

28 For example, by convening the Climate Engineering Conference series, see http://www.ce-conference.org

29 These included, among other things, the precautionary principle, respect for existing international laws, multilateral, transparent and accountable deliberations, and an agreed global multilateral governance mechanism (ETC Group, 2017b).

Assembly or one of its bodies, or possibly regional bodies (for example, the South Asian Association for Regional Cooperation (SAARC), the Association of Southeast Asian Nations (ASEAN) or the African Union). Given that geoengineering has profound implications for climate governance in the short- to medium term, as well as broader potential implications for planetary conditions in the long term, a new multilateral approach may be needed to ensure inclusive decision-making consistent with sustainable development.

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For further reading

This policy brief provides a high-level overview of the most important issues that geoengineering brings up for policy-makers. Much has been written on geoengineering across many disciplines. To avoid duplication and to ensure this brief is accessible and concise, this paper does not focus on technical detail. The following reading list includes more detailed analyses in different areas and may serve as a starting point for interested readers and further policy research.

General

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Legal issues

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Appendix 1: Sources of funding for geoengineering research (based on preliminary desk review)[30]

Governments

- Academy of Finland's research programme on climate change (FICCA)
- German Federal Ministry of Education and Research
- Japanese Ministry of the Environment and Ministry of Education, Culture, Sports, Science & Technology
- Research Council of Norway
- UK Research Councils
  - Engineering and Physical Sciences Research Council (EPSRC), Natural Environment Research Council (NERC), Economic and Social Research Council (ESRC), Arts and Humanities Research Council (AHRC), Science and Technology Facilities Council (STFC)
- US
  - National Aeronautics and Space Association (NASA), NSF, Central Intelligence Agency (CIA) and National Oceanic and Atmospheric Association (NOAA) have all been involved
- UNESCO (previous funders to SRMGI)

Private institutions/individuals/foundations

- Bill and Melinda Gates Foundation
- Carnegie Council (funding C2G2 Initiative)
- Children's Investment Fund
- Environmental Defense Fund
- Heinrich Böll Foundation
- Hewlett Foundation
- Norfolk Charitable Trust
- Sloan Foundation
- The Carbon War Room
- The InterAcademy Panel
- The Open Philanthropy Project
- The Royal Society
- The World Academy of Sciences
- Zennström Philanthropies

Sources:

Environmental Defense Fund (https://www.edf.org/climate/geoengineering)
Gordon Research Conferences (https://www.grc.org/climate-engineering-conference/2017/)
Open Philanthropy Project (https://www.openphilanthropy.org/research/cause-reports/geoengineering#footnote7_16rrdhe)
The Climate Geoengineering Governance (CGG) project (http://geoengineering-governance-research.org)
The ETC Group (http://www.etcgroup.org/funding)
The Guardian (https://www.theguardian.com/environment/2017/mar/29/criticism-harvard-solar-geoengineering-research-distorted)
The Keith Group (Harvard University) (https://keith.seas.harvard.edu/FICER)
The Integrated Assessment of Geoengineering Proposals Project (http://www.iagp.ac.uk)
The Solar Radiation Management Governance Initiative (http://www.srmgi.org/about/)
The Stratospheric Particle Injection for Climate Engineering Project (http://spice.ac.uk)

30 Additional research will be necessary to identify which organisations are actively engaged in funding ongoing geoengineering research.

Appendix 2: Summary of CDR options

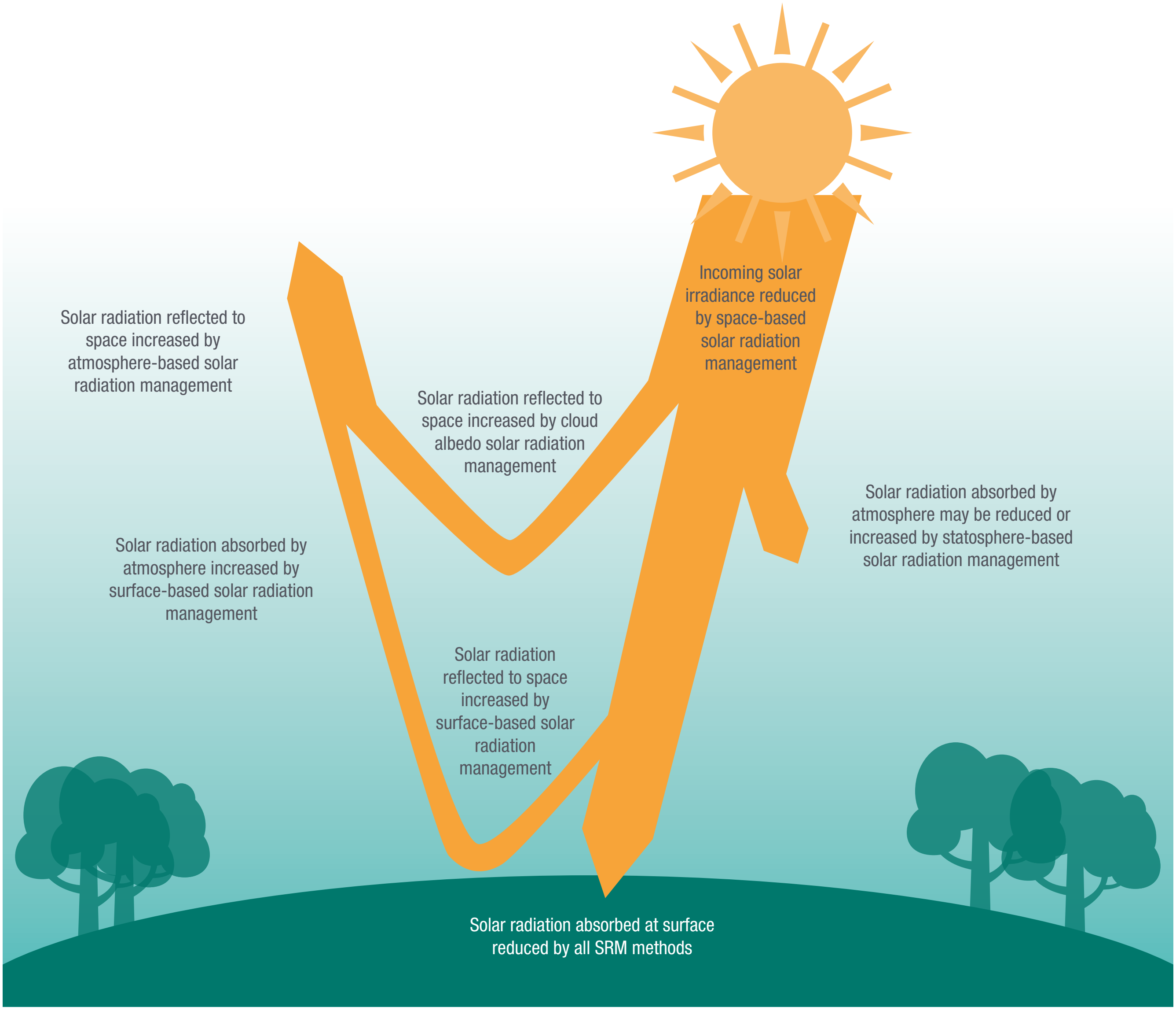
Table A1: Summary of CDR options

	Land	Ocean
Biological	Afforestation and land use Biomass/fuels with carbon sequestration	Iron/phosphorous/nitrogen fertilisation Enhanced upwelling
Physical	Atmospheric CO_2 scrubbers ('air capture')	Changing overturning circulation
Chemical ('enhanced weathering techniques')	In-situ carbonation of silicates Basic minerals (incl. olivine) on soil	Alkalinity enhancement (grinding, dispersing and dissolving limestone, silicates, or calcium hydroxide)

Source: Royal Society (2009)

Appendix 3: Different levels of intervention of SRM

Figure A1: Illustration of different levels of intervention of SRM



Source: Based on Royal Society (2009)

Appendix 4: Summary of potential impacts of various geoengineering interventions

In their 2009 report, the Royal Society reviewed literature pertaining to each of the main geoengineering options, evaluating their likely costs, anticipating their environmental impacts and estimating the likelihood of unexpected environmental impacts. In more recent work, Williamson and Bodle (2016) specifically focused on the potential impacts on biodiversity.

Here, key points from both reports are summarised to provide both a general perspective on the consequences of each intervention and examples of the more detailed impacts when viewed through a specific lens (equally valid lenses that we have not assessed here could include ethical, political, or economic impacts).

Note: impacts may be positive or negative (or a complex mixture of both), depending on the context of the intervention (for example, its size, location or duration).

Table A2: Summary of potential impacts of various geoengineering interventions

Intervention	Anticipated impacts	Potential unexpected impacts	Potential impacts on biodiversity	Potential effectiveness
Carbon dioxide removal	**Reduction in atmospheric CO_2 concentrations**	**Various**	**Various**	**Slow, but works in direct opposition to anthropogenic GHG emissions (root cause of climate change)**
Reforestation/ Afforestation/ Land use management for carbon sinks/ Biomass-based interventions (including BECCS and biochar)	Changes in surface albedo, land use, localised ecosystem impacts	Competition with other land uses (and knock-on impacts e.g. on food prices or water resources), CO_2 release during transition period, land grabs, risk of impermanence (CO_2 leaking back to atmosphere)	Significant land use changes could adversely affect existing ecosystems. Knock-on effects could impact neighbouring areas directly and connected areas indirectly (e.g. weather patterns)	Limited – requires substantial land area to have meaningful impact (note current rate of deforestation).
Enhanced weathering (land/ ocean)	Significant impacts associated with mineral extraction (mining)	Mainly biodiversity-related	Primary and secondary impacts on ecosystems uncertain	Limited/moderate – cost and scale (and impacts of the latter) are challenges
Ocean manipulation (fertilisation with iron, phosphorus, or nitrogen, or promoting mixing)	Localised (bio-) chemical perturbations, increased acidification of mid- and deep ocean. Significant impacts associated with mineral extraction (mining)	GHG release, route to permanent storage uncertain	Primary and secondary impacts on ecosystems uncertain	Limited/moderate – cost, scale and demonstration emissions reductions are challenges
Air capture	Impacts associated with competition for resources (e.g. land and water)	Impermanence (CO_2 leaking back to atmosphere) depending on storage solution	Impacts of conflicting or changing resource use	Limited/moderate – cost and scale are major issues. Currently depends on deployment of wider (fossil-fuelled) carbon capture and storage

Intervention	Anticipated impacts	Potential unexpected impacts	Potential impacts on biodiversity	Potential effectiveness
Solar radiation management	**Reduction in amount of solar radiation absorbed at the surface (leading to lower increase in surface temperature)**	**All SRM methods suffer from the termination effect and are likely to impact regional climate and other associated natural systems (e.g. precipitation, hydrological cycle, carbon cycle, nitrogen cycle)**	**Various**	**Rapid, but does not address increased atmospheric GHG concentrations. Globally averaged SRM can mask large regional climate changes (because of spatial difference between SRM impacts and GHG impacts)**
Land-/ Ocean-based methods	Increased reflection of solar radiation from the surface	Impacts on existing land use/ land users/ ecosystem services	Context dependent (whitening buildings → limited impacts; adding reflective foam to ocean surface → severe impacts on many species)	Limited/ moderate (depends on coverage and net increase in reflectivity)
Atmosphere-based methods	Reduction of total light reaching surface/ increase in proportion of diffuse light	Long atmospheric residence time atmosphere means dislocation between perturbation and response. Significant regional inequities	Material added to the atmosphere has potential for localised pollution effects (e.g. ozone degradation)	High potential for limiting temperature increase, potentially at cost of spatially unequal impacts on climate and other natural systems.
Space-based methods	Reduction of total light reaching surface/increase in proportion of diffuse light	Unknown	Unknown	High potential for limiting temperature increase. Technically feasible but politically unlikely.

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