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GEOENGINEERING AND PUBLIC POLICY

Framing, Research, and Deployment

Ina Möller

27.1 Introduction

In the general landscape of fear, hope, anxiety, and optimism surrounding climate change, the concept of 'geoengineering' is making its way into public policy. Geoengineering is a term that has been widely used to describe a collection of large-scale interventions that aim to deliberately alter the Earth's climate. The concept usually invokes techno-scientific imaginaries like space mirrors, ocean current engineering, stratospheric aerosol injection, or large-scale afforestation. In their anticipatory nature, retroactive function, and unprecedented scale, these imaginaries can be considered different from the conventional mitigation strategies that are commonly used to avoid or prevent the release of greenhouse gases.

The techniques that have been imagined under the concept of geoengineering are often divided into two categories: the large-scale, *ex post* removal and storage of atmospheric carbon dioxide (carbon dioxide removal, or CDR), and the increase of planetary reflectivity (solar radiation management, or SRM). Of these two approaches, CDR has become the most widely discussed and accepted category, featuring prominently in the scenarios of the Intergovernmental Panel on Climate Change (IPCC) as 'negative emissions technologies'. CDR approaches often rely on enhancing or imitating the capacities of ecosystems to absorb and store greenhouse gases, for example by increasing the amount of trees that can absorb carbon dioxide, or by creating 'artificial trees' – machines that filter greenhouse gases from the ambient air. By contrast, SRM describes a group of interventions that cool the planet by increasing the Earth's reflectivity. SRM techniques are less socially accepted, and remain most strongly associated with the geoengineering term. One frequently discussed option in this group is the dispersal of reflective aerosols in the Earth's stratosphere, imitating the cooling effect of large volcanic eruptions. But also approaches like increasing the reflectivity of glaciers, sea ice, or marine clouds fall under this category.

More importantly, geoengineering is a term that evokes contestation and debate. Often users of the term employ it to highlight how a given technique is unusual or different from conventional climate policy. By contrast, employing the terms 'mitigation' or 'adaptation' to describe any of the above techniques usually emphasizes commonalities and familiarity with

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what is already known. The exact collection of techniques and approaches that fall under the concept of geoengineering therefore depends on the perspective of the term's user, and the context and purpose of the conversation.

In general, the use of geoengineering techniques to address climate change is still speculative. Large-scale afforestation in China comes closest to what can be considered a 'real-life' case of geoengineering, although this policy has been implemented under the banner of ecological restoration (Cao *et al.*, 2011). Nascent examples of policies explicitly relating to the reversal of global warming are emerging mainly in relation to net-zero strategies. The United Kingdom is situating itself as a front-runner in acknowledging the need for large-scale greenhouse gas removal and supporting targeted research on technologies like bioenergy with carbon capture and storage (BEIS, 2020). In the United States, policy is moving ahead to address atmospheric carbon dioxide removal by providing tax incentives for activities like direct air capture (Congressional Research Service, 2021). In the European Union, the Commission has launched a policy package to encourage its agricultural sector into 'carbon farming' at a large scale (European Commission, 2021). Yet in general, research shows that countries are still facing much uncertainty about what role such techniques can and should play in a wider policy portfolio (Schenuit *et al.*, 2021). Similar to other speculative technologies like hydrogen and nuclear fusion, public policy around geoengineering is still very much at the beginning of things.

This chapter provides an overview of key issues that have been studied with respect to the governance of geoengineering and provides directions for future areas of inquiry. It is divided into three sections, each discussing a distinct question that is relevant to public policy making on this subject. Section 27.2 addresses the fundamental question of how geoengineering is defined and how this impacts public policy making. Section 27.3 addresses expectations about how public policy should govern geoengineering research and development. Section 27.4 addresses imaginaries of where and when geoengineering might take place, sketching out the key debates, anticipated actors, and the geopolitics involved in geoengineering deployment.

27.2 Defining Geoengineering: A Basis for Public Policy?

What one means by 'geoengineering' and whether one chooses to use the term at all is often subject to extensive debate, as well as a matter of political aim, personal conviction, and professional background. The idea of 'geoengineering' the climate has passed through a century-long definitional evolution, being part of scientific discourse ever since anthropogenic climate change was discovered. In this evolution, the concept has been associated with different political aims and used (or shunned) by different actors. This section gives a short outline that highlights how the evolution of definitions is relevant to public policy making.

27.2.1 The Definitional Evolution of Geoengineering

Our contemporary understanding of geoengineering is strongly shaped by a widely cited Royal Society report that defined geoengineering as "the deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming", dividing the various imagined techniques into SRM and CDR (Shepherd *et al.*, 2009, p. ix). Yet discussions of the idea can be traced back to the beginning of the 20th century. In the wake of disastrous global cooling events caused by volcanic eruptions, the Swedish climatologist Svante Arrhenius speculated how burning coal might lead to a virtuous cycle of global warming. He argued that in this cycle, "we may hope to enjoy ages with more equable and better climates … when the earth will bring forth more abundant crops than at present" (Arrhenius, 1908, p. 63). Decades later, as climate science recognized the detrimental effect of burning fossil fuels, scientists began to think the other way around and search for ways to reduce global temperatures. In 1965, the White House published a document in which it described possibilities to bring about "countervailing climatic changes" such as increasing the reflectivity of the Earth, in order to address excessive global warming (President's Science Advisory Committee, 1965, p. 127). Nine years later, in the aftermath of the global oil crisis and the Watergate Scandal, American and Russian atmospheric scientists discussed the notion of purposeful climate influence and stabilization, and the problems that humanity might face when trying to use climate control (Budyko, 1974; Kellogg and Schneider, 1974).

The idea to purposefully intervene in the climatic system was continuously engaged with over many years, regularly appearing in policy relevant reports such as those published by the United States National Academy of Sciences (1983, 1992, 2015a, 2015b). Geoengineering encompasses grand narratives of space mirrors and the control of ocean currents, as well as highly technical discussions around chemical reactions and intellectual property rights. It is also an area subject to moral debates and heated discussions about what is right and what is wrong (Oomen, 2021). And while the conventional story is that geoengineering was subject to a 'taboo' lifted by atmospheric chemist Paul Crutzen in 2006 (Lawrence and Crutzen, 2017), the increase of scientific and political engagement that provides the justification for writing this chapter is also due to long-term changes in the standing of climate science vis-à-vis the state, and short-term changes in the composition and dynamics of related knowledge networks (Schubert, 2021; Möller, 2022).

Since the publication of the IPCC's Special Report on 1.5 Degrees, the usefulness of geoengineering as an umbrella term that covers all forms of global climatic intervention has become questioned. In 2018, the IPCC declared that it would no longer use the term. Instead, it highlighted a need for more nuance and differentiation between individual approaches, pointing to the fundamental differences between technologies that remove carbon dioxide and technologies that increase the reflectivity of the Earth (de Coninck *et al.*, 2018). Within each of these categories, public discourse is now finding new umbrella headings. Thus CDR (also termed 'greenhouse gas removal' or 'negative emissions technologies') is being separated into 'nature-based' or 'natural climate solutions' on the one hand, and 'technological solutions' on the other (Bellamy and Osaka, 2019). Meanwhile SRM (also termed 'climate stabilization' or 'solar radiation modification') is becoming separated into the global approach of 'solar geoengineering' (mostly equated with 'stratospheric aerosol injection'), and smaller-scale approaches that use techniques like marine cloud brightening or ice preservation.

The categories that I will use in this chapter differ somewhat from the categories described above. Given that all geoengineering techniques aim to change the global climate, they would all need to be implemented at a globally relevant scale – regardless of how they physically function with respect to the Earth's radiation balance, or whether they use 'technological' or 'natural' approaches. Implementation at this scale is always, fundamentally, a question of political organization. I thus distinguish geoengineering techniques by their political mode of operation, based on how many actors it takes for the technique to cause change at a climatically relevant scale. Depending on the answer to this question, each technique can be conceptualized as a centralized, an industrial, or an emergent intervention (see Box 27.1). Distinguishing techniques according to this dimension serves as a helpful tool when thinking about cross-cutting public policy issues in the rest of the chapter.

Box 27.1 Geoengineering Techniques and Their Political Mode of Operation

Geoengineering refers to large-scale, deliberate, and mostly speculative interventions to change the Earth's climate. Approaches are commonly grouped by their physical mode of operation, separating between techniques that remove greenhouse gases from the atmosphere (CDR) and techniques that increase the reflectivity of the Earth's surface (SRM). All aim to reverse or counterbalance the effect of global warming *after* greenhouse gases have been emitted and require large-scale implementation in order to affect planetary systems.

For a discussion on public policy, I find it helpful to group these technologies by their (potential) political mode of operation.

Centralized interventions are techniques with concentrated implementation power, requiring only a few actors in a few places to affect change at the planetary scale. Ideas might include engineering the movement of ocean currents, placing reflective mirrors in space, or spraying reflective aerosols in the atmosphere.

Industrial interventions are techniques that require the alignment of a large but limited number of actors (notably governments and industry) in a limited number of places to affect change at the planetary scale. Ideas might include planting large amounts of biomass, harvesting and storing the resulting carbon in liquid or solid form, artificially changing the pH level of the oceans, or increasing the reflectivity of polar ice sheets.

Emergent interventions are techniques that require many actors in many places to affect change at the planetary level. Ideas might include adding restoring degraded ecosystems, painting infrastructure white, or growing light-coloured crops.

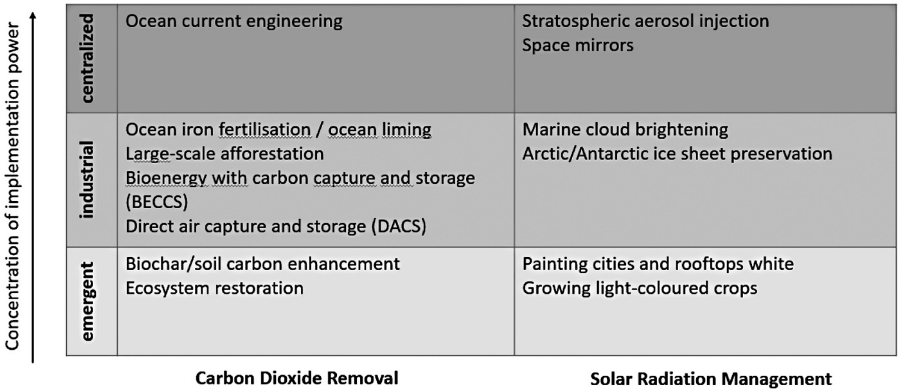

Figure 27.1 An overview of geoengineering techniques that distinguishes their physical mode of operation as well as their political mode of operation.

Note: The graph sorts techniques according to the anticipated concentration of implementation power, referring to how many actors are likely needed to affect global change using one technique.

27.2.2 Geoengineering as Public Policy

The definitional evolution that geoengineering has experienced over the years is reflected in the way that public policy making has interacted with it. At the height of the scientific engagement with the term (accompanied by a row of outdoor experiments with ocean iron fertilization, a hype around their potential to generate carbon credits, as well as an emerging anti-geoengineering discourse among civil society organizations), geoengineering was also addressed in international policy making fora. In 2008, parties to the Convention on Biological Diversity (CBD) as well as parties to the London Convention and London Protocol on marine dumping (LC-LP) adopted decisions to discourage private enterprises from conducting ocean iron fertilization. Both conventions later followed up with additional decisions and amendments that would regulate geoengineering and marine geoengineering activities more widely, though not imposing a ban on scientific research (Ginzky and Frost, 2014; Talberg *et al.*, 2017).

A decade later, the term was again introduced to an international forum. In 2019, Switzerland and a diverse coalition of countries tabled a resolution at the United Nations Environment Assembly (UNEA), calling on the United Nations Environment Programme to write a report that would elucidate scientific and governance questions related to geoengineering. In the ensuing discussions, a small group of countries engaged with the proposal over several days. While the United States and Saudi Arabia argued against introducing international regulation on geoengineering that might affect their discretion, the European Union and Bolivia feared that initiating regulatory activities under UNEA might weaken existing regulation under the Biodiversity Convention and the London Protocol (Jinnah and Nicholson, 2019). As is often the case in negotiations, interests were defended on the basis of procedure. The key arguments that were brought forth in public revolved around timing, forum, and definition, with concerns expressed about the institutional mandate and the choice of terminology in defining what the resolution should be about. Despite extensive efforts to accommodate everyone's preferences, the final draft was eventually withdrawn from the negotiation table (McLaren and Corry, 2021a).

The contrast between the engagement of the parties at the Biodiversity Convention/London Protocol and at the UNEA points toward the importance of scientific discourse in shaping the foundations of public policy and governance. In what can be described as a kind of 'de facto governance', authoritative assessments like those of the Royal Society, the National Academy of Sciences, and the IPCC set the scene for what public institutions can do and how negotiators can argue (Gupta and Möller, 2019). Thus, an assessment that highlights the need to engage with the governance of geoengineering provides the basis for passing a resolution, while an assessment that dismisses the usefulness of the entire concept puts the need of such a resolution in question.

'Public policy' around geoengineering therefore starts not on the desks of policy makers, but much earlier – in the editorial boardrooms and coordination meetings of authors contributing to authoritative scientific reports, and in the discursive structures that they build on (Boettcher, 2020). These discourses provide the starting point for any public policy discussion. At the same time, these discourses often work with concepts and problem definitions that need to be adjusted to match the political and institutional context of decision makers (Möller, 2020; Boettcher and Kim, 2022). Whether geoengineering is then conceptualized as a political project distinct from other forms of climate policy making, or whether it is unravelled into a multitude of technicalities and accounting procedures, affects the content and scope of public policies. For both scholars and practitioners, keeping an eye on these definitional struggles is therefore key to understanding where, when, and how 'geoengineering' enters the realm of climate change policy making.

27.3 Geoengineering Research: An Issue for Public Participation?

Accompanying the imaginary of geoengineering has always been the advancement of scientific research. As a techno-scientific project, methods of intentionally controlling the climate have been depicted in experimental designs and engineering ideas that range from plans to fertilize the Earth's oceans, to imitating the cooling effect of large volcanic eruptions (Martin, 1990;

MacMartin, Caldeira and Keith, 2014). In the scholarly literature as well as in public debate, any kind of outdoor experimentation linked to these plans is often considered the frontier – and the bone of contention – of geoengineering research.

27.3.1 Outdoor Experiments and the Social Licence to Operate

In 2021, geoengineering made the front cover of newspapers around the world due to a confrontation between Harvard University researchers and an international network of civil society organizations. The Harvard research group had planned to launch a small balloon experiment with the help of a private space company based in Kiruna, northern Sweden. They were met by much public attention across the Swedish media and were requested to cancel their experiment in a letter signed by representatives of the indigenous Sami Council. In the end, the researchers withdrew, stating that they would make efforts to improve their public consultation and participation process before attempting any further experiments of the kind (Goering, 2021).

What happened in Sweden is essentially a repetition of similar attempts to do outdoor experimentation with geoengineering techniques in the past (also see Low, Baum and Sovacool, 2022). A series of tests involving ocean iron fertilization between 1993 and 2009 met with increasing resistance from civil society organizations who gathered around an anti-geoengineering rhetoric (Strong *et al.*, 2009). They eventually brought their concerns to the attention of international policy makers, resulting in the earlier discussed resolutions and decisions on geoengineering regulation under the Biodiversity Convention and the London Protocol (Fuentes-George, 2017). Shortly after, a British team of scientists planned to conduct an outdoor experiment linked to the delivery mechanisms that would be needed to conduct stratospheric aerosol injection. Their plan to hoist a one-kilometre-long water hose into the sky was again met with protest from anti-geoengineering civil society groups, and eventually cancelled (although the reason given by the scientists was a problem of patents and intellectual property rights) (Pidgeon *et al.*, 2013).

Within this setting of scientific experimentation and civil society protest, experts often highlight the need for public participation in the governance of geoengineering research. Underlying the discussion around public participation is often a quest to obtain consent, or a 'social licence to operate' in the research and deployment of geoengineering technologies (Lenton *et al.*, 2019). A large amount of literature thus engages with scoping public opinions and organizing workshops in which to discuss geoengineering scenarios. A 2021 report by the US National Academy of Sciences stated that public engagement in solar geoengineering research is necessary for building trust and understanding what 'the public' considers permissible and what not (NASEM, 2021, p. 178). Also in the realm of CDR, public participation is coming to be seen as an important part of ensuring the social legitimacy of greenhouse gas removal technologies (O'Beirne *et al.*, 2020).

Yet given the global reach of geoengineering, it is often uncertain who this public might be and what the implications are of introducing the idea of climate control to audiences who were previously unaware of this possibility (Bellamy and Lezaun 2015). Furthermore, contemporary societal arrangements often work with models of representative democracy. If officials who represent the interests of their voters are in a position to make informed decisions, lack of explicit public engagement on the research and use of geoengineering would not necessarily be undemocratic (Wong 2016). The crux of this discussion – similar to many other issue areas of policy making – would then boil down to how legitimate these decision makers, and the systems in which they operate, are perceived to be. Given the less-than-impressive results that governments have delivered on climate change policy so far, key issues in the coming debate around incentivizing and governing both CDR and SRM technologies will likely revolve around climate communication and trust in the actors involved (Colvin *et al.*, 2019; Raimi, 2021).

27.3.2 Designing Governance for Research

The assortment of proposals for how to design governance for geoengineering research is as proliferous as proposals of how to design research itself. One recent review in the field of solar geoengineering maps out the different formats of governance that have been proposed, covering state and non-state actor engagement, possible moratoria on outdoor research and their problems, the legitimation of decision making procedures, the regulation of commercial actors and intellectual property, as well as compensation mechanisms. It concludes by highlighting a need for more research on the role that non-state actors could take in governing geoengineering, as well as the need for the IPCC to dedicate an explicit focus on SRM (Reynolds, 2019). Another review maps the landscape of principles, frameworks, procedures, and institutions that have been suggested and critically assesses their shortcomings in terms of Western norm reproduction, instrumentalist conceptions of public engagement, and the problematic separation of indoor and outdoor research. This review points to the need for a top-down, international research governance regime that can explicitly reflect on the emerging social, ethical, political, and technical implications of geoengineering research, as well as regulating knowledge production on geoengineering more generally (McLaren and Corry, 2021b).

These different conclusions are examples of different understandings of how, and more particularly why, geoengineering should be governed. In their analysis of governance rationales for solar geoengineering, Aarti Gupta et al. (2020) depict a continuum of reasons for why scholars propose governance mechanisms in the first place. Simply put, it ranges from the desire to enable research to the desire to restrict it, with more nuanced rationales in between that focus on ensuring adequate oversight or safeguarding the interests of under-represented populations. These variations in governance rationales somewhat explain the wide variety of governance proposals that exist in the geoengineering literature, and point to the underlying values that necessarily shape discussions around geoengineering research and its regulation.

The attention given to outdoor experiments, public participation, and governance design obscures some of the more inconspicuous, but more potent, aspects of geoengineering research. Climate modelling groups across the world routinely calculate what would happen if the Earth were engulfed in a layer of sulphur particles, if its oceans were mixed with hundreds of millions of tonnes of lime, or if it were covered in half a billion hectares of forest or biofuel crops. Such global modelling experiments have become authoritative sources of scientific knowledge that inform policy making at the highest levels, most notably through the regular assessment reports of the IPCC (Beck and Mahony, 2017; Hansson *et al.*, 2021). In graphs and scenarios, they show the outcome of a whole range of what one might call 'Earth Experiments', evoking (but rarely engaging with) important questions about responsibility and justice (Stilgoe, 2016; Rubiano Rivadeneira and Carton, 2022).

The way in which digital 'Earth experiments' are communicated differs, depending on which modelling group is engaging with which type of model, and how much access they have to authoritative authorship positions. What sort of digital experiment is considered 'feasible' or 'realistic' and therefore deemed 'policy relevant' is essentially down to the value judgement of the individual modelling group. Thus the modelling culture of influential groups like the Integrated Assessment Modelling community, which has prime access to writing the IPCC's Working Group III report on mitigation, has had a substantial impact on contemporary climate policy (Cointe, Cassen and Nadaï, 2019). Led by the International Institute for Applied Systems Analysis (IIASA) in Austria, this community has focused primarily on the role of terrestrial carbon removal, with some of its leading figures identifying a combination of biomass production with carbon capture and storage (BECCS) as an 'overlooked' but highly promising solution to the climate change problem early on (Kraxner, Nilsson and Obersteiner, 2003). The resulting focus of the IPCC's AR5 report on afforestation and BECCS as key elements of future climate trajectories has influenced climate policy around the world, leading to a flurry of net-zero targets that rely on unprecedented amounts of afforestation and biomass production (Peters and Geden, 2017; Rogelj *et al.*, 2021). The political implications of these targets remain to be seen, but they do raise an important question about the power that expert-driven climate modelling has on contemporary climate policy (Beck and Oomen, 2021).

27.4 Geoengineering Deployment: A Task for Policy Cooperation?

Despite frequent efforts to separate research from deployment, the potential use of geoengineering is a constant companion in any discussions around its governance. Particularly among the approaches labelled SRM, the global nature of interventions like stratospheric aerosol injection raises questions as to whether there can be a real separation between research and deployment, and whether the two would not need to be governed hand in hand. Meanwhile in the area of CDR, discussions revolve around creating incentives for upscaling techniques like afforestation or carbon capture and storage in order to meet the tall order of going 'net-negative' by the middle of this century, and how such an enormous effort would be coordinated and financed.

27.4.1 Common Concerns: Slippery Slope, Moral Hazard, and the Question of Justice

One core theme that has shaped this discussion is the idea of a 'slippery slope'. By talking about a slippery slope, geoengineering critics refer to the possibility that setting up mechanisms that allow or incentivize research may lead to the creation of vested interests or a socio-technical lock-in, resulting in no other option than deployment (Anshelm and Hansson, 2014; Callies, 2019). The slippery-slope argument is commonly refuted by pointing to examples where investment in a technology did result in failure and abandonment, and some even positing that the investment in geoengineering is actually more of an 'uphill struggle', as there is still very little political and societal interest in these methods (Bellamy and Healey, 2018). Nevertheless, the question of systemic path dependency is worth taking into account. Particularly in the case of CDR, large-scale investment in removing greenhouse gases from the atmosphere could shift a heavy-weight industrial system onto a pathway that is not so easy to reverse, and the systemic consequences of this shift should be taken into account at early stages in the political process.

A second core theme is the idea of 'moral hazard' or 'mitigation deterrence' caused by geoengineering. This concern relates to the possibility that including speculative geoengineering technologies in the climate policy portfolio will result in less efforts to reduce emissions through conventional mitigation (McLaren, 2016; Markusson, McLaren and Tyfield, 2018). Whether this is actually the case is very hard to measure, given that there is no parallel world to compare ours with. Yet learning from other cases in which speculative technologies have been named as key solutions to climate change (notably multi-decade-long discussions about the potential of carbon capture and storage, hydrogen, or nuclear fusion), we may assume that adding CDR or even solar geoengineering to the climate policy agenda is unlikely to accelerate efforts in reducing greenhouse gases emissions. The recent wave of net-zero pledges by companies who continue to invest in fossil fuels seems to support this point (Bhargava *et al.*, 2022). One key thing to note here is that while some studies find evidence against the relevance of moral hazard (e.g. Austin and Converse, 2021), this research rests on the responses of individuals and does not tell us much about the dynamics that take place at a collective level. Collective climate change policy, with its decade long debates about who should be responsible, who should pay, and what kind of information would be needed to ensure action, is subject to a tangle of interests and historical political relations. How these will be affected by the introduction of geoengineering policies is difficult to test or predict based on the responses of individual citizens. Arguably, the largest risk in this realm is the delay of *any kind* of climate policy, be it emissions reduction, carbon removal, or climate adaptation.

A third common theme is the question of intra- and intergenerational justice (see Box 27.2). The potential deployment of a centralized intervention like stratospheric aerosol injection evidently raises questions about who will decide what to do, how much of it, and where and when this will take place. Given stark differences in power and influence between different communities and nations, observers highlight the need to account for the interests of peoples who are not heard or represented in the halls of decision making power. This can usually go either way: for example, while advocates use justice as a way to argue *for* using solar geoengineering (stating that those who are most vulnerable to climate change would also benefit most from a technology like stratospheric aerosol injection), critics highlight the neo-colonial taste of this argument and use it to argue *against* solar geoengineering, given the concentration of political and economic power that such a technique would reinforce (Horton and Keith, 2016; Stephens and Surprise, 2020).

In the area of CDR, concerns around justice relate mainly to issues of land use (particularly land and water grabbing) and what large-scale carbon removal might do to key commodities. Models suggest that industrial-scale use of BECCS or afforestation could raise staple food prices in the Global South by fivefold compared to 2010, and may exacerbate water stress beyond what climate change itself would cause (Fuhrman *et al.*, 2020; Stenzel *et al.*, 2021). Direct air

Box 27.2 Justice and Geoengineering

Centralized interventions like stratospheric aerosol injection are most prominent in the justice discussion, as these raise thorny questions about who can make decisions on behalf of whom, who can be held responsible for side effects, and who should compensate for any harm experienced.

Industrial interventions like bioenergy with carbon capture and storage raise important questions about economic path dependencies and what these might mean for future generations, as well as possible effects on other socio-environmental systems including food and energy. As these industrial interventions require substantial resource use, key concerns revolve around the distribution and respect for land and water rights.

Emergent interventions like biochar or reflective infrastructure are less prominent in the justice debate, but may nevertheless raise questions around how incentives for implementation are distributed. Many of these concerns are not exclusive to geoengineering techniques, but recognizable from other kinds of public policy. It is thus advisable to consider the implications of geoengineering techniques in relation to a wider portfolio of climate-relevant public policy.

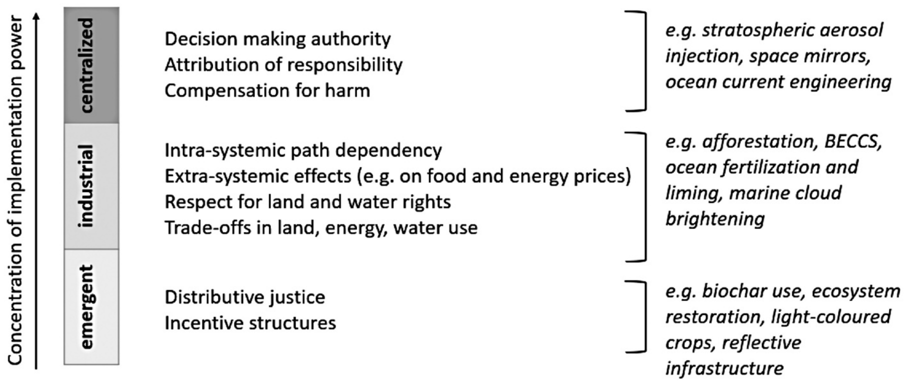

Figure 27.2 An overview of the most pertinent justice concerns associated with different geoengineering techniques.

Note: The listed concerns are not exclusive to the techniques mentioned on the right-hand side of the graph. Rather, the graph highlights the most pertinent justice concerns associated with each type of intervention.

capture would likewise require 12–20 percent of the global energy supply if it is to be globally relevant (Chatterjee and Huang, 2020). Given that any industrial intervention to absorb CO_2 would have substantial effects on global markets, those who are already most vulnerable to fluctuations in prices would likely be the first to feel the effects. On the other hand, given the substantial (and increasing) climate footprint of emerging powers that host a large percentage of the world's poorest people, such techniques are seen as a suitable climate policy for countries like China and India, with the potential to minimize damage to economic growth while supporting environmental restoration efforts (Chen *et al.*, 2019; Weng, Cai and Wang, 2021).

Discussions about justice and geoengineering are always held with the caveat that very few of the people who are spoken about actually participate in the conversation. Future generations are perhaps the most difficult to include as they lack political presence and as it remains notoriously hard to know what the future will bring. Although models can tell us something about the possible (physical) effects of both climate change and geoengineering, they provide a necessarily simplified view of the world. Risks related to economic dependencies, disinformation campaigns, perceived security hazards, and pure bad luck are difficult to account for, and the social instabilities that may or may not be caused by various geoengineering techniques (or indeed, a world without geoengineering in which climate change alone affects these questions) add a significant layer of uncertainty. Yet even when models give reasonable estimates about the future, Western liberal philosophy tends to prioritize the interests of contemporary (human) generations over others. Suggestions to overcome this challenge highlight the need for a more deliberative style of decision making in which the plurality of values is taken seriously (Hourdequin, 2019). In addition, a valuable source of wisdom can be found in the cyclical or spiralling understanding of time held by many first nations communities, an ontology that would enable a more equal evaluation of the interests held by past present and future generations (Winter, 2021).

At the same time, it is worth noting that the expertise produced on geoengineering and climate change science more generally lies firmly in the hand of scientists based in highly industrialized countries (Corbera *et al.*, 2016; Biermann and Möller, 2019). The few studies that do include voices from commonly under-represented communities paint a picture of diverse positions, but also highlight the need to place the various geoengineering techniques in a much larger context than is commonly done. Studies that have tried to gauge perceptions of geoengineering interventions among non-Western publics highlight the variation in viewpoints and philosophical ideas that can be found in these settings, but also mention a commonality that could be characterized as a kind of 'conditional acceptance' within communities that are heavily affected by climate change. Here, geoengineering is seen as a last-resort option in the face of devastating environmental change, but concerns remain around the enhanced economic dependencies, unequal distribution of power, and marginalization or exploitation that these technologies might cause (Winickoff, Flegal and Asrat, 2015; Carr and Yung, 2018; Gannon and Hulme, 2018). More fundamentally, Kyle Powys Whyte (2019) points out that most geoengineering discourses are not set up in a way that would allow marginalized communities like indigenous peoples to properly express their concerns about risk, research, and power. Judging by the perspectives that many of these peoples have on other topics, he argues that geoengineering would hardly be considered a discreet topic in relation to climate justice. Instead, it would form part of a much wider discussion around colonialism and how this has defined and continues to shape indigenous vulnerability to climate change.

27.4.2 Imaginaries of Deploying Solar Radiation Management

Further questions that shape speculation and inquiry around geoengineering deployment revolve around who will develop and use the technology, what their intentions might be, and whether they have the necessary legitimacy to be successful in their endeavour (see Box 27.3). One key imaginary that shapes this discussion in the field of stratospheric aerosol injection is the notion of 'rogue actors'. Because stratospheric aerosol injection is touted as a comparatively simple and cheap technology (involving a few dozen aircraft and a few hundred tonnes of sulphur powder), scientists often point out that basically anyone with a reasonably decent budget, including wealthy individuals, could run a stratospheric aerosol injection operation. This has led governance scholars to speculate about the role of 'green-finger' billionaires, desperate small island states, and environmentally minded non-governmental organizations as potential unilateral deployers of stratospheric aerosol injection (SAI) (Victor, 2008; Millard-Ball, 2012; Reynolds and Wagner, 2019; Schenuit, Gilligan and Viswamohanan, 2021). Although the initiation of an SAI operation through such actors is imaginable, one could also argue that any unsanctioned efforts at manipulating the climate would soon be put to an end by other, more powerful actors (Rabitz, 2016). Furthermore, the upkeep of such an operation would quickly dry out the resources of any individual actor, save large and militarily powerful nations (Smith, 2020). Yet even the incentive of these large powers to unilaterally deploy SAI is questionable, with the social and political costs (including possible trade sanctions, diplomatic isolation, and reprisals in other issue areas) deemed higher than the benefits that any one nation could gain from a non-sanctioned use of the technology (Horton, 2011).

While one could say that unilateral deployment of SAI is possible (though unlikely), it is also unlikely that a multilateral approach to managing this technology will emerge without an urgent reason to do so. Inquiries into the perceptions of policy makers confirm that expectations and social norms play an important role in reasoning about geoengineering. While there is no scientific consensus around the desirability of and need for (research on) centralized forms of SRM, policy makers are cautious about taking a public position on the subject. Rich countries mainly fear that their reputation might be damaged by associating with the topic while poor countries lack the capacity to engage with yet another complex scientific topic

Box 27.3 Anticipated Actors in Geoengineering Implementation

Centralized interventions like stratospheric aerosol injection or ocean current engineering are likely to be implemented by economically and militarily powerful actors, given the long-term upkeep and political controversy associated with these techniques. A coalition of smaller, heavily affected nations might also embark on such an endeavour if they can secure the legitimacy not to face retribution.

Industrial interventions like bioenergy with carbon capture and storage or marine cloud brightening are more comparable to the activities of the oil and gas, timber, agribusiness, and shipping industries. Their expertise and infrastructure is highly relevant if these techniques are to be implemented at a large scale, but would require reorientation through the policies of national governments and the guidelines of finance, insurance, and standard setting organizations.

Emergent interventions like biochar or reflective infrastructure are activities more likely to be led by municipalities, public and private infrastructure owners, and (consortia of) individual land owners. Accompanying all three types of interventions are actors engaging in research and/or advocacy of the various techniques.

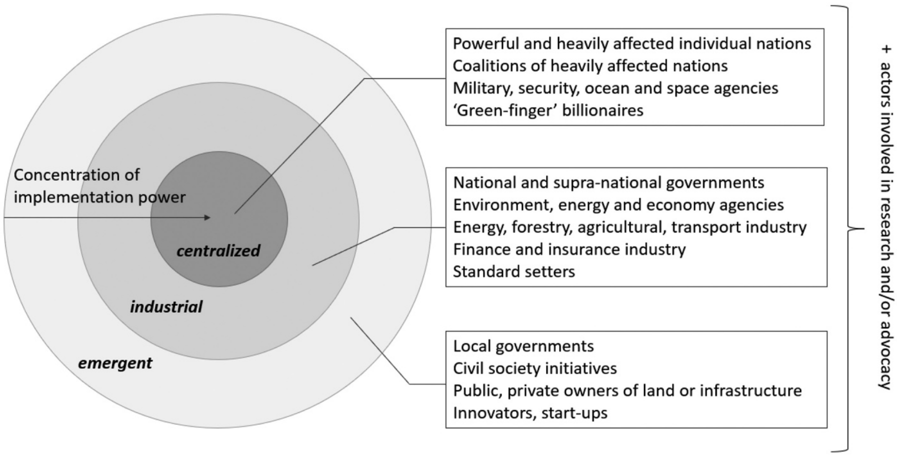

Figure 27.3 Key actors that might be involved in implementing different geoengineering techniques, grouped according to each intervention's political mode of operation.

on their already overburdened climate change policy agendas (Möller, 2020). This caution to engage means that negotiations at the multilateral level are difficult to initiate, and an international agreement on how to govern solar geoengineering is not yet visible on the horizon of international climate negotiations.

In the absence of a multilateral agreement for global-scale solar radiation management, scenarios in which we might still see SRM techniques being deployed are in industrial or emergent form. Climate modellers are increasingly engaging with scenarios of regional cooling, and examples of initiatives are starting to take shape on the ground. Most prominently, a consortium of local government actors, civil society organizations, and scientific institutes has recently embarked on a quest to save the Great Barrier Reef, and within its portfolio of techniques it aims to use marine cloud brightening to provide a cooling umbrella for the region (Tollefson, 2021). Other ongoing endeavours in the use of SRM include plans to save glaciers and ice sheets, such as the one described by the 'Arctic Ice Project' (formerly called 'Ice911'). The principal idea of this non-profit organization is to scatter glass beads on the surface of Arctic sea ice in order to increase its reflectivity and reduce the speed of melting (Arctic Ice Project, 2021). The incentivization of such reflectivity enhancement procedures has also been introduced to the International Standards Organization (ISO), where environmental certification companies from the USA tried to introduce a new standard for measuring organizations' climate footprints. This standard, based on the concept of radiative forcing, would have allowed the inclusion of 'climate coolants' in the calculation of an organizations footprint, enabling the generation of tradeable credits for such projects. Due to concerns about the unintended effects that such a standard might have, the initiative was eventually downgraded to a technical document with no guiding power (Möller, 2021).

27.4.3 Realities of Deploying Carbon Dioxide Removal

In the field of CDR, the discussion around who will deploy negative emission technologies is less about ensuring control and more about creating incentives for investment and upscaling. Removing carbon from the atmosphere at an industrial scale for the sake of permanent storage is not yet financially viable, mainly due to low carbon prices. When looking at carbon removal through land-use change, incentives for afforestation and reforestation are still lower than for deforestation. Although many developed countries (as well as China and India) are reporting net gains in forest cover, the amount of embodied deforestation in their imports has risen, contributing to the overall trend of global forest loss (Hoang and Kanemoto, 2021). In addition, changes in the climate are affecting the frequency of wildfires and forest dieback, further contributing to the release of carbon emissions. More 'technological' solutions to carbon removal are also facing severe challenges. The most viable economic approach envisioned for companies that filter CO_2 from the atmosphere is to turn the carbon into a commodity, selling it on to other companies who use it for the cultivation of algae or (ironically) for enhanced oil recovery (Wilcox, Psarras and Liguori, 2017). The permanence of this absorbed carbon is therefore not guaranteed, and the scale at which these companies are operating is still minimal. In addition, scaling carbon removal and permanent storage faces significant challenges in terms of energy sourcing, the land needed to generate that (ideally renewable) energy, and the infrastructure necessary for CO_2 transportation.

The core actors projected to play a role in the industrial development of CDR are the forest and agricultural sectors, but also the oil and gas industry. The capture of carbon dioxide and its storage underground is a key element of many of the 'technological' solutions that have been put forward. Meanwhile, the primary use of captured carbon is currently in enhanced oil recovery, where underground oil is pumped out and replaced with liquid carbon dioxide. This means that oil and gas companies have both the necessary skill set and the infrastructure to deal with captured carbon dioxide. On the one hand, this is an opportunity because this industry is highly influential and a globally powerful player that – given the right incentives – could contribute substantially to the acceleration of the net-zero transition (Garcia Freites and Jones, 2021). On the other hand, it is a problem because the fossil fuel industry contributes substantially to climate change, and has used the promise of carbon removal for many years in order to avoid any reduction of emissions (Carton *et al.*, 2020). Meanwhile, the forest and agricultural sectors are already well known as actors from previous debates around carbon offsetting, land-use change, and biodiversity conservation. The challenge of reaching net negative emissions by 2050 only increases the demands on these sectors to adapt their practices with environmental goals in mind (von Hedemann *et al.*, 2020). At the same time, they face increasing pressure to produce timber and food for a growing population and – more problematically – highly wasteful consumption patterns among the world's wealthy citizens.

How then do scholars and practitioners propose to overcome these enormous hurdles to CDR deployment? Discussions in this field are akin to classic policy dilemmas already familiar from climate change policy more generally. The availability of finance, for example through an increase in the carbon price, is most often mentioned as an important necessity for improving incentives to invest in carbon removal and storage, and ramping up (voluntary) carbon markets to facilitate the financing and trading of carbon credits is a common solution discussed in climate policy circles (Honneger *et al.*, 2021). But there are also words of caution. Too much focus on carbon is liable to create perverse incentives, negatively affecting communities and livelihoods, heightening the cost of food, and contributing to the further depletion of biodiversity. Therefore scholars argue for separating emission reductions from emission removal targets, providing financing for other environmentally and societally relevant goals, and ensuring that the generation of carbon credits is subject to regulation and monitoring (McLaren *et al.*, 2019; WBGU, 2021). Some say that solutions that generate co-benefits, for example carbon removal techniques that also help to ameliorate soils, should be prioritized (Cox and Edwards, 2019). Most importantly, the upscaling of carbon markets should not justify a continued reliance on fossil fuels, as early climate action would lessen the negative impact of future negative emission technologies (Hasegawa *et al.*, 2021). As this discussion moves from the theoretical to the practical, actors that will be relevant to shaping this trajectory are (re)-insurance companies and standard setting organizations. Together with the targets and goals defined by policy makers, these actors will have an important hand in guiding industry towards large-scale CDR.

27.5 Conclusion and Future Research

Despite the controversy of the concept, geoengineering in various shapes and guises has entered national and international policy agendas. As countries face increasing pressure to act on climate change, large-scale carbon removal and perhaps also large-scale solar radiation management are becoming unavoidable topics. This chapter has laid out how questions around the definition, research, and deployment of geoengineering are affecting public policy agendas. In doing so, it has introduced a political categorization to better discuss the policy implications of different types of geoengineering techniques, distinguishing between centralized, industrial, and emergent interventions. One important thing to keep in mind during this discussion is that all types of geoengineering are still highly speculative, and that the idea of being able to actively engineer the climate is intrinsically linked to the global perspective of climate science. Yet any form of climate policy will always take place in specific local settings, with local actors and local interests involved. Bridging this gap will be a key challenge for policy making. It will also require the support of analysts who can critically reflect on the global solutions offered by climate science, as well as find ways to make these match the needs and limitations of regional, national, and local settings.

Box 27.4 Chapter Summary

- Geoengineering is a contested concept that is usually associated with techno-scientific imaginaries of halting or reversing global warming.
- Public policy needs to be aware of the different meanings and intentions with which the term is used.
- Geoengineering techniques are inherently anticipatory; they shape contemporary policy despite large uncertainties about whether or not they will ever exist.
- To facilitate governance, it is helpful to think about how geoengineering techniques might differ in terms of the political organization of their implementation.

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