16

Governing Experimental Responses

Negative Emissions Technologies and Solar Climate Engineering

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16.1 Introduction

Parties to the 2015 Paris Agreement strive to 'hold . . . the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C' (UNFCCC, 2015: Article 2.1[a]). In response to the growing realisation that atmospheric greenhouse gas (GHG) levels will likely exceed the concentrations associated with these goals, some scientists and others are researching responses that are novel, experimental and technological. They suggest the consideration of intentional, large-scale interventions in earth systems to reduce climate change. Since the mid-2000s, discussions of these 'climate engineering' or 'geoengineering' techniques have steadily moved from the fringes of climate change discourses towards the mainstream.

A seminal 2009 report on climate engineering by the United Kingdom's Royal Society concluded, among other things, that '[t]he greatest challenges to the successful deployment of geoengineering may be the social, ethical, legal and political issues associated with governance, rather than scientific and technical issues' (Shepherd *et al.*, 2009: xiii). Given that some of these proposed techniques appear to have the potential to substantially reduce climate change, while posing risks of their own, climate engineering governance has emerged as a salient issue.

This chapter places the governance of climate engineering in a polycentric governance conceptual framework. Following an introduction to climate engineering proposals and their governance needs, I discuss existing climate engineering governance. The chapter then explores the extent to which climate engineering governance is polycentric, prospects for its future polycentricity and what – if anything – this implies for climate governance more generally.

16.2 Climate Engineering

Proposed climate engineering techniques are diverse with respect to their means of operation, current levels of development and readiness, capacities to reduce climate change, forecast costs, speeds, co-benefits, environmental and social risks and uncertainties. They also vary in their political aspects, including their incentive structures, likely roles of public and private actors, degrees of integration in climate policy discourses and governance needs.

Climate engineering would operate through one of two distinct primary means. The first would be to remove carbon dioxide from the atmosphere and sequester it for a long time (McNutt *et al.*, 2015a). Generally, these ‘carbon dioxide removal’, ‘greenhouse gas removal’ or ‘negative emissions technologies’ (NETs) would – relative to the second primary means of climate engineering – be expensive, act slowly, pose low and local risks that differ among the specific proposed techniques, address climate change close to its cause and intervene less forcefully into natural systems.

Brief descriptions of some proposed NETs, their capacities to remove carbon dioxide and their risks can concretise the concept. First, machines could extract carbon dioxide from the air and then store or reuse it. This ‘direct air capture’ appears to have great sequestration capacity, poses little risk besides that of leakage (carbon dioxide is poisonous at high concentrations) and is presently being developed by a few private firms (Marshall, 2017). Second, plants could be grown – a process that captures atmospheric carbon dioxide – and then burnt to produce energy while the emitted carbon dioxide could be captured and stored. At large scales, this ‘bioenergy with carbon capture and storage’ would require large amounts of arable land, constraining its capacity, increasing food prices and threatening biodiversity. Bioenergy with carbon capture and storage would, like direct air capture, also have leakage risks. Third, the locally limiting nutrient could be added to marine waters, increasing the growth of plankton that indirectly incorporate atmospheric carbon dioxide. Such ‘ocean fertilisation’ would pose risks to marine ecosystems and would be difficult to verify. It was the subject of more than a dozen field trials in the 1990s and 2000s, but interest has since declined due to public controversy and disappointing and uncertain results. Finally, industrial processes could accelerate the natural weathering of minerals, through which carbon dioxide transforms into a dissolved salt. Some tests have been conducted, but scaling them up would be challenging. Although each NET could contribute to lower atmospheric GHG concentrations, none could resolve the problem singlehandedly.

NETs have become partially integrated into the climate policy mainstream. The more optimistic emissions scenarios include large amounts of NETs. Specifically,

the Representative Concentration Pathways used by the Intergovernmental Panel on Climate Change (IPCC) that are expected to keep global warming below 2°C assume the implementation of bioenergy with carbon capture and storage at remarkable scales, on the order of 10 gigatons of carbon dioxide per year (van Vuuren *et al.*, 2011; Fuss *et al.*, 2014: 851). To give a sense of that magnitude, this would be more than double the mass of current annually global harvested crops, which is four gigatons per year (Alexander *et al.*, 2017: 194). Many observers note that such assumptions might have problematic consequences: unrealistic expectations could be fuelled and emission abatement efforts could be undermined (Anderson and Peters, 2016). Since the mid-2000s, NETs have become the subject of dedicated but modest funding mechanisms, academic research, attention from advocacy organisations and limited private investment.

NETs would have governance needs akin to emissions abatement. This is because, for both practices, the actor implementing the NET would bear the costs and risks while the entire globe would share the benefits of lower GHG concentrations. NETs thus present a global collective action problem and the associated challenge of free-riders. To be effective, governance would need to: incentivise NETs' research, development and implementation; monitor, report and verify their use; assure those who use them that others are not free-riding; minimise environmental and social risks; and compensate those who have been harmed. As with other climate-related technologies, governance should also facilitate knowledge transfer and learning, including internationally. Together, these needs imply that NETs governance could in principle consist of a mix of global, national, subnational and private governance instruments and institutions.

The second general means of climate engineering would be to block or reflect a small portion of the planet's incoming solar radiation, which would counteract climatic change (McNutt *et al.*, 2015b).[1] Generally, these solar climate engineering (SCE) or 'solar radiation management' techniques would – relative to NETs – be inexpensive and rapidly effective, pose serious environmental and social risks, treat merely the symptoms of climate change and intervene forcefully into natural systems. At a gross level, SCE appears to be able to greatly reduce climate change and concomitant risks. Presently, SCE remains largely outside of mainstream climate policy discourses, although that appears to be slowly changing. Research funding has been ad hoc, advocacy organisations' interest has been minimal and there are no SCE businesses. Dedicated, explicit outdoor experiments of SCE techniques are planned but have not yet been conducted (Keith, Duren and MacMartin, 2014; Gertner, 2017).

Two proposed SCE techniques hold particular potential. In the leading one, small aerosol particles would be injected into the stratosphere, blocking some

incoming sunlight and cooling the planet, similar to how large volcanoes do. This 'stratospheric aerosol injection' appears to be technically feasible and has the capacity for nearly unlimited cooling. The second technique would involve spraying seawater upward as a fine mist. After evaporation, the remaining salt particles would act as cloud condensation nuclei and cause marine clouds to be brighter. Such 'marine cloud brightening' faces technical hurdles, but could, in theory, compensate for perhaps 1°C or 2°C warming.

As noted, SCE would pose environmental and social risks. First, it would unevenly compensate anthropogenic changes in temperature and precipitation, resulting in areas with residual climatic anomalies. Second, the leading candidate material for stratospheric aerosol injection – sulphur – could damage stratospheric ozone, although other materials are under consideration. Third, countries and other actors might disagree about the timing, form and intensity of SCE implementation, a possibility made more problematic by the apparent low direct financial costs and technical feasibility of SCE. Fourth, if SCE were to stop suddenly for some reason after a long implementation period at a strong intensity, the planet's climate would rapidly experience the previously suppressed climate change. Finally, as with NETs, SCE's development might undermine conventional emissions abatement efforts.

The primary governance needs of SCE are distinct from those of NETs and emissions abatement, for two reasons. First, not only SCE's reduction of climate change but also its environmental risks would be global. This implies that governance of SCE implementation would ultimately need to likewise be global and – given the high stakes – likely state-centric. Second, SCE appears to have such low direct implementation costs and to be so effective at reducing climatic anomalies that it could – at least in principle – be in the self-interest of a single country to implement it unilaterally and bear all the financial costs. Thus, instead of the free-rider problems of emissions abatement and NETs, SCE would face a 'free-driver' problem, in which states would provide it excessively and prematurely (Weitzman, 2015). The primary governance challenge would thus be one of mutual restraint (Barrett, 2007). At the same time, SCE shares some other governance needs with NETs. For example, within countries, its research and development would still be a public good and thus need to be encouraged through, for example, grants. Internationally, research should be coordinated and collaboration facilitated. Governance should also reduce environmental and social risks as well as arrange compensation for any harmed groups. These secondary governance activities need not be centralised, but might benefit from it.

16.3 Current Governance

16.3.1 International Legal Instruments and Institutions

Given the transboundary and even global impacts of both climate change and climate engineering, as well as the low level of national and non-state climate engineering governance activity, existing international legal instruments and institutions offer a foundation for climate engineering governance (Reynolds, 2014). Their implications vary for the different climate engineering techniques, and especially between NETs and SCE. Furthermore, because existing international law was not developed with climate engineering in mind, interpretation is central. A central challenge here is that both climate engineering and the climate change that it would seek to reduce pose environmental risks. Indeed, both phenomena satisfy definitions of 'pollution', 'adverse effects' and 'damage' in various international environmental agreements.

International law presumptively permits countries to undertake and to allow actions conducted by legal persons under their control. Indeed, the sovereign right of states to exploit their natural resources as they see fit is a foundational principle of international law (UNGA, 1992: Annex I, Principle 2). At the same time, if their own activities or activities under their control pose risks of significant environmental harm that would cross borders or affect areas beyond national jurisdiction, countries have the obligation to prevent and reduce such transboundary harm by exercising due diligence pursuant to customary international law. This duty includes taking measures to prevent or reduce potential harm; review by national authorities; prior environmental impact assessment; notification of, consultation with and cooperation with the likely affected public and countries; emergency plans; and monitoring. Some climate engineering activities, particularly the large-scale field research and implementation of SCE and of ocean fertilisation, would pose transboundary risks, and – in those cases – countries would have these obligations. If a state's actions that are contrary to international law were to have negative transboundary impacts, then the customary international law of state responsibility would be applicable. In that case, the state should: cease the activity; assure that it will not recur; provide reparations through restitution, compensation and satisfaction; and offer victims access to legal remedies.

Among treaties, the regime established by the United Nations Framework Convention on Climate Change (UNFCCC) appears to be a logical home for international climate engineering governance. Yet the climate agreements are, in some ways, ambiguous in this respect, which is largely understandable given that the first two of the three treaties of the regime were developed before climate engineering was subject to more than marginal consideration. The UNFCCC does not restrict how states may help stabilise GHG concentrations, and the Paris

Agreement largely leaves it up to individual states how they will contribute to limiting global warming to its targets. Furthermore, the institutions related to the UNFCCC – such as its Conferences of Parties and its Subsidiary Body for Scientific and Technological Advice – have been noticeably silent on climate engineering.

Nevertheless, NETs do fall clearly within the purview of the UNFCCC. The objective of the UNFCCC is the rapid 'stabilisation of atmospheric GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system', and the acceptable means of doing so explicitly include the enhancement of sinks and reservoirs of GHGs (UNFCCC, 1992: Articles 2 and 4.1[d]). Parties to its 1997 Kyoto Protocol agree to research and promote 'carbon dioxide sequestration technologies' (UNFCCC, 1997: Article 2.1[a][iv]). Furthermore, the Paris Agreement calls for limiting global warming by achieving 'a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases' (UNFCCC, 2015: Article 4.1). In order to integrate NETs into the climate regime, parties to these treaties should agree upon the extent to which they may rely upon NETs in their emissions reporting and trading systems. Parties to the UNFCCC have already adopted rules with respect to land use, land use changes and forestry – which resemble NETs – but this has been protracted and challenging. Such a process for the diverse proposed NETs would likely be as well.

How the climate regime might govern SCE is much less clear. The technologies have a less clear relationship with the objective of the UNFCCC. Specifically, SCE could decrease 'anthropogenic interference with the climate system' caused by GHGs, in turn allowing for greater atmospheric GHG concentrations. Regardless, SCE could contribute to the the objective of the Paris Agreement (UNFCCC, 2015: Article 2.1[a]). Both agreements are implicitly favourable to at least the research and development of SCE. The UNFCCC's hortatory passages call for states to rapidly and inexpensively minimise the adverse effects of climate change 'so as to ensure global benefits at the lowest possible cost', for anthropocentric reasons and balanced with goals that include economic development and food production (UNFCCC, 1992: Articles 1.1, 2, 3.1 and 3.3). In addition, UNFCCC parties made multiple commitments to undertake research and to develop and diffuse new technologies (UNFCCC, 1992: Articles 4.1[g] and [h], 4.3, 4.7, 4.8, 4.9 and 11.1). SCE research, development and possible implementation could contribute to these goals.

Among climate engineering techniques, ocean fertilisation is an exception in that international legal institutions have given it specific attention. In the late 2000s, two private firms announced their intentions to fertilise the ocean in order to sell carbon credits, despite the uncertainty regarding the effectiveness of the techniques, the

possible environmental impacts and the marketability of the credits. The United Nations General Assembly and an ad hoc consultative group to the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) released statements that emphasised both the potential and the risks of ocean fertilisation (UNGA, 2007; IOC-UNESCO, 2008: 2–3). The parties to the London Convention and London Protocol, which regulate ocean dumping, established a working group and the Legal Intersessional Correspondence Group on ocean fertilisation, and agreed that ocean fertilisation should not be allowed except for legitimate scientific research (IMO, 2008). They later developed an assessment framework for determining whether a proposed activity qualifies as legitimate scientific research (IMO, 2010). In 2013, the London Protocol parties approved an amendment, not yet in force, to that agreement. This would apply a similar standard to the broader category of 'marine geoengineering', which could include some forms of both NETs and SCE undertaken in the marine environment (IMO, 2013). Furthermore, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection of the International Maritime Organisation established a working group on marine geoengineering to, among other things, help operationalise this amendment (GESAMP, n.d.).

Meanwhile, the parties to the Convention on Biological Diversity (CBD) expressed their concern and requested that countries not allow ocean fertilisation, except for small-scale studies, until there is an adequate scientific basis, consideration of the risks and effective regulation (CBD COP, 2008: paragraph C.4). They went on to later broaden their statement to include all climate engineering activities that may affect biodiversity (CBD COP, 2010: Paragraph 8[w]). In 2016, they reaffirmed their previous statements while also noting that more research is needed (CBD COP, 2016). The CBD statements are the only outputs of an international legal institution with widespread participation that address climate engineering in its entirety.

The United Nations Convention of the Law of the Sea is another international legal agreement with broad participation that could contribute to international climate engineering governance. This could apply to a wide range of climate engineering techniques because its parties have committed to protect and preserve the marine environment, which is usually understood to include the marine atmosphere (UNCLOS, 1982: Article 192; Frank, 2007: 12). In this, they are to – among other things – 'prevent, reduce and control pollution of the marine environment from any source', including from land-based sources (UNCLOS, 1982: Article 194). Notably, the definition of pollution in the United Nations Convention of the Law of the Sea implicitly includes GHGs, global warming and – if it were likely to have deleterious effects on people and the marine environment – climate

engineering (UNCLOS, 1982: Article 1.1[4]). Applying such provisions to climate engineering would require a difficult balancing of the impacts on the marine environment of climate change and climate engineering.

A handful of other international legal instruments could also play roles. First, many climate engineering techniques would satisfy the definition of 'environmental modification' under the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (UNGA, 1976: Article II). The parties to this agreement would be obligated to refrain from military and hostile uses of climate engineering that would have widespread, long-lasting or severe effects as their means of harm (UNGA, 1976: Article I.1). At the same time, the treaty calls for the peaceful development of environmental modification (UNGA, 1976: Preamble and Article III). Second, if stratospheric aerosol injection SCE were to contribute to the depletion of stratospheric ozone – as sulphur, the leading candidate substance, might – then the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol could regulate the activity. Third, stratospheric aerosol injection SCE with sulphur could also fall within the purview of the Convention on Long-Range Transboundary Air Pollution and its protocols. Under this treaty, European and North American countries agreed to reduce acid rain precursors, including atmospheric sulphur. Finally, the Governing Council of the United Nations Environment Programme (UNEP) developed nonbinding Provisions for Co-operation between States in Weather Modification. As with the Environmental Modification Convention, many climate engineering methods – especially SCE – would satisfy this document's definition of weather modification (UNEP, 1980: footnote). It is supportive of weather modification 'dedicated to the benefit of mankind [*sic*] and the environment', asks states not to use it to harm other states' environments and areas beyond national jurisdiction and calls for international cooperation and communication (UNEP, 1980: paragraphs 1[a], 1[b], 1[f] and 1[h]).

Finally, some intergovernmental institutions have engaged with climate engineering. For example, the IPCC held an expert meeting on climate engineering and is expected to dedicate a chapter to the topic in its next Assessment Report (Edenhofer *et al.*, 2012; Goldenberg, 2016). Meanwhile, the IPCC special report on the 1.5°C goal will, among other things, assess the ability of NETs to contribute to the goal (IPCC, 2016). UNESCO hosted an expert meeting, whose participants proposed an international climate engineering research programme sponsored by UNESCO's Intergovernmental Oceanographic Commission, the International Council for Science and the World Meteorological Organization (UNESCO, 2010). That latter institution is developing a position statement on climate engineering (Bruintjes, 2015). In this process, it will reportedly cooperate with the

World Climate Research Programme, the Intergovernmental Oceanographic Commission, the International Maritime Organization and other bodies.

16.3.2 Countries and the European Union

States either are involved in climate engineering governance only at the margin or are absent entirely. In addition to participating in the CBD and London Convention and London Protocol negotiations described earlier in this chapter, a few countries have taken specific actions in this area. The governments of both the United Kingdom and Germany have issued reports, offered dedicated funding for research and issued official statements that cautiously support the consideration of climate engineering (UK Department of Energy and Climate Change, 2010; Schütte, 2014). The governments of China, Finland, India, Japan and Norway have financially supported climate engineering research. The Russian government's comments on an IPCC report encouraged continued research into climate engineering as a 'possible solution' (IPCC, 2014: 2). In the United States, a report issued during the last month of the Obama administration recommended federal funding of climate engineering research (US Global Change Research Program, 2017). By contrast, Bolivia's leadership has opposed climate engineering (Estado Plurinacional de Bolivia, 2011). Finally, although the European Union (EU) is not a country, its leadership establishes the contours of the climate policies of its Member States in a quasi-federal manner. The EU has funded two international climate engineering research projects and its Commissioner for Climate Action and Energy implied that NETs might be part of the future climate policy mix of the EU (Neslen, 2015).

16.3.3 Non-state Actors

Some non-state actors have contributed in various ways to climate engineering governance (see also Zelli, Möller and van Asselt, 2017). This section reviews their activities in five categories, although the lines distinguishing them are not completely clear. First, several scientific and professional organisations have made assessments, offered recommendations and taken positions. The reports of the United Kingdom's Royal Society and the US National Academies have been particularly influential (Shepherd *et al.*, 2009; McNutt *et al.*, 2015a, 2015b). Other organisations that have taken positions on climate engineering include the American Meteorological Society, the American Geophysical Union, the Institution of Mechanical Engineers and the International Commission on Clouds and Precipitation of the International Association of Meteorology and Atmospheric Sciences. In the case of ocean fertilisation, more than a dozen universities and other

research institutions formed the In-Situ Iron Studies Consortium in order to promote research, including compliance with the standards of the London Convention and London Protocol. Each of these scientific and professional organisations called for further climate engineering research.

Policy-oriented and advocacy non-governmental organisations constitute another broad category of non-state actors. The Carnegie Climate Geoengineering Governance Initiative, led by a veteran international climate policy negotiator, facilitates the development of climate engineering governance in the global policy arena. The Solar Radiation Management Governance Initiative increases the involvement of developing countries and their residents in SCE discourses. In addition, a few environmental groups have taken a range of positions regarding climate engineering. Those whose platforms are more oriented towards the inherent value of nature and are more critical of existing social and institutional arrangements more frequently oppose climate engineering (e.g. Greenpeace International, 2010). By contrast, those that are more concerned with reducing demonstrable negative impacts on people, species and ecosystems and are less critical of existing arrangements are more likely to cautiously endorse climate engineering research (e.g. Environmental Defense Fund, 2015). Environmental groups are generally more strongly opposed to (or less supportive of) SCE than NETs (e.g. Friends of the Earth UK, 2009). Regardless, even these environmental organisations dedicate few resources to climate engineering, and many are reluctant to discuss it (Nicholson *et al.*, 2013). Finally, from a different perspective, the conservative think tank American Enterprise Institute housed a small project on climate engineering for a few years.

Third, a handful of philanthropists and foundations have supported climate engineering research. For example, Bill Gates has done so via a special fund, and Richard Branson has offered a $25 million prize for a scalable and sustainable NET. Other sources include more established ones such as the Hewlett and Sloan foundations.

Businesses – primarily small ones – have invested in NETs but are absent from SCE. This is consistent with the prospect that the former, like mitigation, could be a profitable enterprise in the presence of a sufficiently large carbon price, whereas there will likely be little direct financial incentive for the latter. As noted earlier, the proposals of two now-defunct firms to commercialise ocean fertilisation catalysed its governance through international legal instruments and institutions, and a third company's actions generated further controversy. One of these first two – Climos – developed a code of responsible conduct of ocean fertilisation (Climos, 2007). Other small businesses are developing direct air capture and enhanced weathering with an eye towards eventual profit. Among large firms, Shell issued a report on net zero emissions

that includes NETs in several scenarios, but its chief climate change adviser is sceptical of SCE (Shell, 2016; Hone, 2017).

Scholars are the final category of non-state actors who have participated in climate engineering governance. Of course, many of them have written articles, chapters and books in the natural and social sciences that might satisfy the definition of *governance*. They have also contributed to the activities of scientific and professional organisations described earlier. Some have proactively helped build bridges from the present absence of dedicated legal instruments and institutions to a future of international governance. For example, the Forum for Climate Engineering Assessment at American University expands and strengthens the discussions of climate engineering and its governance. Other scholars have proposed general principles for climate engineering, emphasising transparency, public participation and independent assessment (MacCracken *et al.*, 2010; Long *et al.*, 2011: 13–14; Rayner *et al.*, 2013). These principles are now being detailed as a proposed code of conduct for climate engineering research that is based upon international environmental law (Hubert, 2017).

16.4 Analysis

This volume describes and assesses polycentric theories of climate governance in which decision-making sites are plural, diverse and multilevel. In these, climate governance is not enacted monocentrically via national and international law, but instead through a dynamic and innovative transnational network of governing rules, institutions and actors who govern in divergent ways (see Chapter 1).

The present governance of climate engineering is consistent with a polycentric view, in that numerous varied governing units operate at multiple scales and relate to each other non-hierarchically while remaining fairly autonomous within their own domains. However, from a perspective that is somewhat sceptical of the polycentricity of SCE governance, climate engineering governance could be seen as polycentric merely by default. The technological proposals that constitute climate engineering arose in a context of existing governing instruments and institutions that had been developed for other purposes and that climate engineering and its constituent elements happen to transect. The fact that numerous international legal instruments and institutions with diverse objectives, scopes, degrees of legalisation and participation would govern climate engineering activities could be a haphazard outcome rather than a polycentric one. However, this interpretation of polycentric governance relies on a narrow, legal understanding of governance.

An alternate – and arguably more accurate – perspective rests on a broader understanding of governance. Seen through this lens, the previous section shows

that heterogeneous intergovernmental, national and non-state actors have taken steps to intentionally direct their own and others' behaviour so that climate engineering will be more likely to develop responsibly. They have sometimes done so in ways that are innovative, arguably due to climate engineering's novel and dynamic character. For example, the UNFCCC and the IPCC are gradually incorporating NETs, while parties to the CBD voice concern regarding climate engineering more generally. Meanwhile, some countries, the EU and philanthropists are funding research, and various non-state actors help set the agenda, broker knowledge and suggest foundational norms from the bottom up. Ultimately, the resulting governance remains inchoate and inconsistent.

Climate engineering governance exhibits three specific characteristics that are at least indicative of polycentric governance. First, these instances of governance are, as Ostrom suggested, developing within an overarching set of rules, in this case international environmental law. When they have substantially diverged, it has often been due to differing interpretations of legal principles and instruments in a *de novo* situation. Second, governing actors have experimented under these dynamic and uncertain conditions. For example, the amendment to the London Protocol would expand the application of the treaty beyond marine dumping to all 'marine geoengineering'. Third, these actors have responded to each other, via processes of mutual adjustment. The dynamic between the parties to the CBD and those to the London Convention and London Protocol, as they negotiated their regulatory boundaries with respect to marine geoengineering from 2007 to 2013, is illustrative of this.

On the other hand, upon closer investigation, the latter two of these three characteristics that indicate polycentricity are less convincing. Although governing actors have experimented, this has not been the 'typical' policy experimentation that Ostrom had in mind, in which roughly similar governing units independently try different approaches to a given problem, and subsequently mutually learn. And although they have adjusted to one another, instead of learning and collaboration that usually constitutes adjustment in theories of polycentric governance, this adjustment appears necessary under legal and scientific uncertainty.

We can expect climate engineering to change in the future, both technologically and socially. How might climate engineering governance respond? In the relatively short term, it appears likely to continue to be polycentric, if not increasingly so. The various proposed techniques pose multiple opportunities and challenges, and innovation's dynamism calls for governance practices that can experiment and adapt. In fact, the speed of technological change often surpasses the ability of governance to adapt, presenting legal challenges and regulatory dilemmas (Collingridge, 1980; Brownsword, 2008). Not only are the usual sites of hierarchical and static governance (e.g. intergovernmental and national actors) poorly

structured to govern in this way but their leaders also have little incentive to tread into this politically treacherous terrain (Horton and Reynolds, 2016). Instead, a wider array of non-state actors – including funders, research institutions, publishers, investors and entrepreneurs – could play substantial roles in coordinating climate engineering activities, fostering cooperation and ensuring responsible practices. As these activities expand, for-profit actors will likely assume a higher profile, particularly in relation to NETs (but see Reynolds, Contreras and Sarnoff, 2017). To some extent, national and subnational actors can manage some of climate engineering's local environmental and social impacts. Furthermore, several international institutions have remits that touch upon climate engineering, and these bodies can be expected to compete and cooperate in contributing to governance. Even if these diverse governing actors did seek centralised and harmonised governance, reaching agreement in such an uncertain and contested terrain would be difficult. Heterogeneity is likely to persist.

The case of ocean fertilisation lends support to this expectation of continued or growing polycentricity. That technology was researched and debated, and its governance developed, earlier and to a greater extent than the other proposed climate engineering technologies. Notably, although it is an NET, its governance needs resemble those of SCE: it would pose environmental risks in areas beyond national jurisdiction and researchers once believed (but no longer do) that it could greatly reduce climate change at low financial costs (McNutt *et al.*, 2015a: 47–53). Its governance is both more mature and noticeably more polycentric. Here, numerous and varied intergovernmental bodies, national governments, scientific and professional societies, environmental organisations, businesses and scientists have each exercised governance authority within their domains in ways that are alternately mutually reinforcing and partially conflictual.

16.5 Conclusions

In the longer term, there might be limits to this polycentricity. According to models, NETs should scale up dramatically in order to prevent dangerous climate change. Given the costs and local risks, states and other actors will be reluctant to provide such a public good without incentives to do so and assurances that others are likewise contributing. Although the bottom-up (but still centrally coordinated) Paris Agreement might offer a sufficient framework to facilitate NETs, more centralised mechanisms such as an international carbon price will be needed to grow if NETs are to scale up in practice. In the case of SCE, the long-term limits of polycentric governance are even clearer. On the scale of outdoor experiments that would have global effects, central coordination would be necessary to, at the very least, ensure that the tests do not interfere with one another. More importantly,

activities that would affect the global climate would need some sort of international agreement in order to be perceived as legitimate. Because climate has impacts on core national interests, such as food production and extreme weather events, states – especially the powerful ones – will likely insist upon taking the lead in this process. Polycentric governance would be poorly suited to resolve possible strategic conflicts among states.

The implications of the governance of climate engineering for that of climate change more generally are uncertain, as the two phenomena have distinct histories and trajectories. The rise of concerns regarding anthropogenic climate change in the late 1980s quickly led to an international treaty that attracted universal participation. Subsequent governance was assumed – at least implicitly – to be global and hierarchical to some degree. Roughly 15 years later, both the uncertainty of the Kyoto Protocol's actual impact as well as the need for adaptation, which is less amenable to international governance, became clear. Consequently, the assumptions regarding centralised climate governance began to yield insights regarding the reality and potential of polycentric governance (see e.g. Prins *et al.*, 2010). By contrast, as described earlier, discussions of climate engineering arose within and across an already diverse governance landscape. However, in the long run, climate engineering – and especially SCE – appears likely to require a form of governance that is substantially more monocentric than is in existence in the world today. This need is more acute if we are to achieve the goals of the Paris Agreement.

Note

1. Cirrus cloud removal is a third distinct means, but is less well developed than the first two and has governance needs much like those of SCE.

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