1

Introduction

Climate change poses serious risks to humans, other species, and ecosystems, and is a major contemporary international political and policy-making issue. United Nations (UN) Secretary General António Guterres – among others – calls it “the defining issue of our time” (United Nations 2018). Leaders of several states, particularly in northern Europe, assert that responding to climate change should form a basis of transformed economies and polities. International discussions toward cooperation in preventing and reducing it are contentious, highlighting and often exacerbating divisions between developing and industrialized countries, including among China, the United States (US), and the European Union (EU).[1]

Numerous diverse experts have for thirty years emphasized the necessity of preventing and minimizing anthropogenic – that is, human-caused – climate change by reducing the emissions of greenhouse gases. However, emissions abatement to date has been much less than needed and will almost certainly continue to be so. Faced with the prospect of dangerous impacts, scientists, political leaders, advocates, and other informed observers have acknowledged that other actions will be needed. Over the last twenty years, state and nonstate actors have increasingly taken steps to adapt to a changed climate. More recently, it has become apparent that we will need to remove greenhouse gases from the atmosphere in large quantities through negative emissions technologies (NETs). Yet even with these additional measures, the risks of climate change – especially to the already vulnerable – remain great.

Some scientists and others are now considering and researching a more drastic category of responses to climate change. This “solar geoengineering” would block or reflect a small portion of incoming sunlight, cooling the planet and reducing climate change. The leading suggested method would mimic volcanoes, whose fine dust naturally lowers global temperatures for a year or two after large eruptions. Similar aerosol particles injected into the upper atmosphere would have a comparable effect. Another method would involve spraying seawater upwards as fine droplets might brighten low-lying marine clouds, which would reflect more

[1] The distinction between developing and industrialized countries is decreasing but remains useful.

sunlight. Current evidence from modeling and natural analogs indicates that some forms of solar geoengineering could effectively reduce climate change, be technologically feasible, have low direct costs, act fast, and be reversible in their climatic effects. Moreover, they could manage climate change risks in ways that the other responses cannot. As it is presently understood, solar geoengineering would necessarily affect the entire world's climate, raising questions such as international decision-making. Furthermore, large-scale outdoor experiments and full implementation would pose environmental risks and social challenges of their own. It is somewhat unclear how to proceed with governing solar geoengineering.

The first substantial report on geoengineering, from the Royal Society in 2009, concluded that "The greatest challenges to the successful deployment of geoengineering may be the social, ethical, legal and political issues associated with regulation, rather than scientific and technical issues" (Shepherd et al. 2009, ix). This remains true a decade later. Who, if anyone, has the legitimate authority to make decisions regarding intentionally changing the world's climate? Would the threat or onset of extreme climate change justify doing so? If solar geoengineering is as inexpensive and technologically feasible as it presently appears, how could the international community restrain a state or other actor that intended to deploy it? How can research reduce uncertainties without unduly increasing the likelihood of future deployment? Does the consideration of solar geoengineering displace already insufficient emissions abatement efforts? If solar geoengineering were implemented, how could we ensure that it would not suddenly stop, causing drastic climate change? If leaders of a country claimed that solar geoengineering had harmed it, who would be responsible? Would the deployer be liable for damages? Is there a role for commercial actors, and if so, could policy prevent the rise of an influential solar geoengineering lobby? Would solar geoengineering constitute an unacceptable change in the relationship between humanity and nature, or merely an acknowledgment of a change that has already taken place?

Because solar geoengineering poses both great potential and risk, it warrants some form of governance. Yet this is challenging for several reasons. First, decision-making in this area is a trade-off between the risks of climate change and those of solar geoengineering. Although every decision is, at some level, a risk-risk trade-off, the stakes here are particularly great (see Graham and Wiener 1995; Chhetri et al. 2018). Second, much remains uncertain. We know that our greenhouse gas emissions will change the climate and that this will pose risks. Yet uncertainty compounds as one's consideration sequentially moves from scenarios of future population and economics, to those of greenhouse gas emissions, to atmospheric concentrations, to climatic changes, to responses, and to the ultimate impacts. What's more, solar geoengineering itself has not been substantially tested outdoors. Third, the temporal dimension is complicated. The effects of emissions, of our responses to climate change, and of scientific and technological research usually are evident decades after the initial activities. Furthermore, although governance of an emerging technology such as solar geoengineering can – in principle – be more effective when designed and implemented earlier, little is known of its potential, risks, and costs at that early stage (Collingridge 1980). Fourth, the very idea of solar geoengineering is unsettling. It lies orthogonal to many cultural, political, ethical, and legal frameworks, particularly those that underlie contemporary environmentalism (Reynolds 2017, 805–8). As a result, it frequently provokes sharply divergent – and sometimes trenchant – reactions.

This book discusses the governance of solar geoengineering. It is primarily descriptive: How is solar geoengineering governed? It is secondarily analytical: What are the opportunities and challenges? Can existing governance instruments and institutions be adapted, or are new ones justified? Tertiarily, it is prescriptive: How should solar geoengineering be governed? Although these questions largely concern law, a substantial portion of governance is through nonlegal means, such as norms, principles, codes of conduct, private regulation, and nonstate institutions. Governance is further shaped by politics, ethics, and economics. Outdoor activities are more consequential and controversial, and thus receive more attention in this volume. Given that large-scale research and deployment would have transboundary if not global effects, international relations and international law come to the forefront.

This book has two central messages. First, although solar geoengineering might seem both outlandish and contrary to common sense, we should take its potential seriously. Climate change poses serious risks, and emissions abatement, adaptation, and NETs are likely to be insufficient. Because solar geoengineering has the potential to reduce climate change, how it is researched, developed, and possibly deployed could offer large relative benefits on – or impose substantial negative impacts on – people, other species, and ecosystems, especially the most vulnerable among them. Second, solar geoengineering and its governance pose genuine challenges, and these warrant careful thought. When I first began to investigate the topic, questions of decision-making, blame for harm, undermining abatement efforts, and preventing sudden and sustained termination struck me as insurmountable barriers and reasons to consider foregoing the possibility. Yet the longer I researched, thought, and wrote, the more that I came to see them as challenges that are not wholly unlike what has previously confronted humanity, which, by muddling through, has more or less managed them.

After this brief opening, Chapter 2 introduces climate change and solar geoengineering. By necessity, this includes some background on climate, why and how it is changing, and the risks that this creates. I also discuss the means, potentials, limitations, and forecasts of the other responses to climate change: emissions abatement, adaptation, and NETs. Chapter 2 then offers a brief history of solar geoengineering and descriptions of several specific solar geoengineering methods. The evidence of their effectiveness, physical risks, social challenges, and economic value constitute the remainder of the chapter.

The most prominent concern regarding solar geoengineering is that its consideration would undermine efforts to reduce greenhouse gas emissions. Chapter 3 opens with a review of this – here called the "emissions abatement displacement concern." I then contrast it with two known similar phenomena and summarize existing relevant public opinion data. An extended logical exercise identifies how any undesirable emissions abatement displacement could arise. The chapter then considers some possible policies to manage emissions abatement displacement and closes with a discussion of the cultural and political bases of concern.

Because large-scale solar geoengineering activities would – as it is presently understood – necessarily be an international phenomenon, Chapter 4 considers its international relations. This begins with a theoretical analysis of the diverse problem structures of solar geoengineering and the other responses to climate change. Solar geoengineering could produce problematic international relations, which are Chapter 4's subsequent topic. Evidence from theoretical models of state behavior is then summarized.

International law is a system of norms, rules, procedures, and institutions through which states mediate their relations and try to prevent and resolve conflicts. It, especially international environmental law, is central to solar geoengineering's governance. Chapters 5 through 8 concern how international law would and could apply to solar geoengineering. Chapter 5 begins with an introduction to how international law operates and continues by discussing general principles of international law, customary international law, nonbinding multilateral environmental agreements, and intergovernmental organizations. International law of the climate and atmosphere is the topic of Chapter 6, and Chapter 7 considers how international human rights law could contribute to the governance of solar geoengineering. Chapter 8 takes on various other relevant multilateral agreements, including those concerning the sea, states' procedural obligations in environmental matters, and biodiversity.

Early outdoor solar geoengineering activities will be small scale and not pose chances of transboundary impacts. They will be governed by national law, which is more specific and strongly enforced than its international counterpart. Chapter 9 offers US law as a case study. This is because the US environmental legal regime is among the most elaborate and because solar geoengineering research is presently moving forward most rapidly there, at least relatively speaking. I apply US environmental law concerning the air, endangered species, weather modification, marine activities, and prior assessment to solar geoengineering.

Governance is more than law and includes nonlegal instruments and nonstate actors. Chapter 10 addresses how nonstate actors have contributed to the governance of solar geoengineering and could still do so. It begins with a description of the concepts and theory behind nonstate governance. I then summarize existing proposed principles and a code of conduct for geoengineering. An analysis then concludes that nonstate governance can play an essential role in solar geoengineering governance.

Chapters 11 and 12 concern two topics that are often invoked in the solar geoengineering governance discourse yet only infrequently explored in any depth. These are sufficiently detailed that my prescriptive suggestions are presented in these chapters instead of Chapter 13. The first of these is the roles of nonstate actors, and especially commercial ones. Chapter 11 begins by considering concerns that nonstate actors might implement solar geoengineering. However, they are likely to play roles – most likely as contractors in public procurement – in research, development, and possible deployment. A leading way in which commercial and other nonstate actors are governed in an innovative domain, such as that of solar geoengineering, is through the policies for intellectual property, particularly patents. Some challenges that intellectual property related to solar geoengineering would pose, as well as a handful of proposals for how to manage these, are discussed. I then put forth a proposal for a research commons for intellectual property related to solar geoengineering.

The second common, insufficiently researched topic is compensation for harm that could result from outdoor solar geoengineering activities. Would those who undertake or approve such activities be liable, especially for transboundary harm, and should they be? If not, should those who have been harmed be otherwise compensated, and if so, how? Chapter 13 provides overviews of the challenges that this would face and of existing international law as a vehicle for liability. I then offer initial proposals for compensation for harm from large-scale outdoor research and solar geoengineering deployment. The recommendation for the former is more specific, whereas that for the latter remains a conceptual framework.

Existing norms, rules, procedures, and institutions appear to be insufficient to effectively govern solar geoengineering in the longer term. In Chapter 13, I suggest what could be done to help ensure that solar geoengineering is researched, developed, and – if appropriate – used in ways that improve human welfare, are sustainable, and consistent with widely shared norms. These are divided into rough stages of small-scale outdoor research, small-scale research, and deployment.

Before proceeding, I wish to make some of my beliefs and assumptions clear and explicit. Normatively, I am consequentialist and welfarist. I believe that policies should be designed and implemented in ways that are expected to increase people's well-being. This should not be a mere brute summation of individuals' quantified utility, or worse, financial wealth. At the very least, there is a strong argument for equity weighting, in which those who are worse off are given disproportionate consideration. Furthermore, future people have value, as do the many nonmaterial things – including justice, security, the natural world, interpersonal relations, and personal experiences – that people consider important.

Second, I generally assume that actors, including states, pursue their diverse goals in a context of incentives and constrained by limited resources. This rationality offers substantial explanatory and predictive power and is a good – albeit imperfect – starting point for understanding interactive behavior. It is "weakly" rational in that it further assumes only reflective actors and complete, transitive, and sufficiently time-consistent preferences. I do not assume "strong" rationality, in which actors always consciously assess the expected outcomes of all options and choose, sensibly and without bias, the one with the greatest expected payoff. Furthermore, larger institutions, such as states, are arguably more rational than individuals due to collective and structured decision-making processes. At the same time, one should be vigilant for institutional failures and outcomes that appear collectively irrational.

Third, a project such as this is inherently speculative. As emphasized, climate change, the responses to it, solar geoengineering, and international relations are all uncertain, yet decision-makers must consider the long term. I try to focus on what I believe to be a reasonable range of possible scenarios, giving greater attention to those that seem more probable while not neglecting the less probable, but potentially relevant, ones.

All writers balance accuracy with brevity. I thus must explain how I use certain words and phrases, lest I either repeat disclaimers and clarifications or risk ambiguity.[2] "Climate change" and "global warming" are used largely interchangeably, with a bias toward the former due to its appropriately greater breadth. "Solar geoengineering" is the intentional modification of the Earth's radiative balance, excluding changes to greenhouse gases (see Heyward 2013; Boucher et al. 2014). This encompasses large-scale actions that would reflect or block some incoming sunlight – which is elsewhere called solar radiation management or modification (SRM), solar climate engineering, albedo modification, climate remediation, and radiation modification measures. Solar geoengineering also includes cirrus cloud thinning, which would allow more infrared radiation – that is, heat – to escape and has similar relevant characteristics. I sometimes use "geoengineering" to encompass a wider range of "deliberate large-scale intervention in the Earth's climate system" (Shepherd et al. 2009, ix), which encompasses both solar geoengineering and large-scale NETs.

The phrase "solar geoengineering" includes the entire set of actual and possible activities, such as brainstorming, serious discussion, lab work, models, small field experiments, climate responses tests, deployment, and assessment activities that would inform and enable such interventions. "Outdoor activities" are both experimental and operative, although the line between these would not be distinct. "Experiments," "tests," and "research" – often preceded by "outdoor" – are intended to be roughly synonymous, as are "implementation" and "deployment" for the use of solar geoengineering to globally counter climate change. Mundanely, "billion" and "trillion" refer to their US or short-scale meanings of 10^9 and 10^{12} respectively.

[2] My word choices are without prejudice to others'.

“Governance” is the goal-oriented, sustained, focused, and explicit use of authority to influence behavior. This can be done through diverse means including unwritten norms, nonbinding principles and rules, laws, administrative regulations, market instruments, procedures, institutions, funding, and international law. Furthermore, governance can be performed by governments, intergovernmental organizations, businesses, other authoritative institutions, and individuals, with others or themselves as the targets. I sometimes use “regulation” to imply governance through binding rules that are developed and enforced by authoritative institutions – especially state ones – that can punish violators. Exceptions are my use of “self-regulation,” “private regulation,” and “meta-regulation.” “Law” is state-made governance that is embodied domestically in legislation, administrative rules, and case law, and internationally in custom, multilateral agreements, general principles, and decisions of international tribunals. “State,” “country,” and “nation” are also meant synonymously, except for US states, which are relevant mainly in Chapter 9. These words are often anthropomorphized to indicate their leaderships.

As this book concerns a speculative topic, I use probabilistic words such as “possible,” “feasible,” and “likely” to describe futures. These represent nothing more than my personal judgment. People of good faith can disagree. I try to use modal verbs to appropriately reflect various degrees of probability and permissiveness, although mistakes are likely. Please do not misinterpret an occasional “will” or “can” as implying precise predictions. Likewise, I mean “proposed” in the broad sense of being suggested by some experts, not necessarily in a pipeline toward expanded activities.

Climate change will affect humans, other species, and ecosystems, and mostly negatively so. Solar geoengineering appears able to reduce climate change, while other responses will almost certainly continue to be inadequate. It will thus receive increasing interest. Because of solar geoengineering’s transboundary impacts, environmental risks, and social challenges, governance will be critical. Broad, in-depth, and long-term conversations are necessary to develop governance that is effective and consistent with widely shared values. I hope that this book offers a useful foundation for these processes.