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### **Solar Climate Engineering, Law, and Regulation**

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### **Abstract and Keywords**

Solar climate engineering—intentional modification of the planet’s reflectivity—is coming under increasing consideration as a means to counter climate change. At present, it offers the possibility of greatly reducing climate risks, but would pose physical and social risks of its own. This chapter offers an introduction to solar climate engineering, and explores its potential, risks, and legal and regulatory challenges. It also contextualizes these proposals with respect to other emerging technologies and the broader socio-political milieu. The chapter discusses the contours of existing and potential regulation, particularly at the international level. These aspects include regulatory rationales, diverse characteristics of proposed regulatory regimes, difficulties in defining the regulatory target, and the management of uncertainty through precaution. The chapter closes with suggested future research directions in the law and regulation of solar climate engineering.

Keywords: climate engineering, geoengineering, climate change, global warming, environment

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## **1. Introduction**

In 1965, as the modern environmental movement was taking shape between the publication of *Silent Spring* (Carson 1962)—a landmark book that helped raise concern regarding environmental degradation—and the first Earth Day in 1970, an authoritative report on pollution was delivered to the office of US President Lyndon Johnson. It contained a chapter on the rising concentration of atmospheric carbon dioxide due to human activities—the first such reporting by a government agency. Although its esteemed authors concluded that this increase could be ‘deleterious from the point of

view of human beings', their proposed response did not refer to abating anthropogenic greenhouse gas (GHG) emissions. Instead,

The possibilities of deliberately bringing about countervailing climatic changes therefore need to be thoroughly explored. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric CO<sub>2</sub> could be produced by raising the albedo, or reflectivity, of the earth ... Thus a 1% change in reflectivity might be brought about for about 500 million dollars a year ... Considering the extraordinary economic and human importance of climate, costs of this magnitude do not seem excessive

(Environmental Pollution Panel, President's Science Advisory Committee 1965: 127).

Such a suggestion might now be dismissed as a relic of mid-century, high modernist technological optimism, captured in slogans of the time such as 'Better Living through Chemistry' and proposals to dam the Grand Canyon. Indeed, the idea of changing the albedo in order to counter climate change was barely discussed for the subsequent four decades.

By 1992, the risks of climate change were recognized as great enough that a treaty—the United Nations Framework Convention on Climate Change (UNFCCC)—was globally ratified in order to facilitate emissions abatement and adaptation to a changed climate. Since then, actual abatement has been very disappointing, with the continued GHG emissions committing the planet to a likely future of dangerous climate change. Yet the proposal to modify the planet's albedo was merely dormant, not dead. After years of infrequent papers and muted conversations at scientific conferences, an atmospheric scientist who had been awarded the Nobel Prize for his work on ozone depletion reluctantly yet forcefully revived the idea, due to what he claimed was 'little reason to be optimistic' about emissions abatement (Crutzen 2006: 217).

Such 'solar climate engineering' (SCE, elsewhere often 'solar radiation management') poses challenges to law and regulation. Its research, and possibly its development, are arguably justified given the rising climate risks and insufficient GHG emissions abatement. Yet its large-scale field research and implementation would pose environmental and social risks of their own, some of which remain highly uncertain or perhaps still unknown. Furthermore, considering the risks of climate change, the divergence of states' interests, the generally protected position of scientific research, and the absence of SCE-specific law, it remains unclear how SCE could be effectively regulated.

This chapter offers an overview of some of the legal and regulatory challenges. Section 2 introduces SCE, and Section 3 places it in the context of other emerging technologies. Because the actual law and regulation of SCE is at present minimal, some attention must then be given to the embryonic politics of SCE. From there, the chapter briefly reviews some relevant existing law and regulation, with a focus on international law. The subsequent section discusses future potential regulation of SCE, including justifications for regulations as well as a review of proposals. The particular challenge of uncertainty and precautionary responses are then considered. The chapter concludes with suggestions for future research in the law and regulation of SCE.

## **2. Solar Climate Engineering**

Climate change is currently the world's greatest environmental challenge and an extremely difficult problem to address. The accumulation of anthropogenic GHGs will increase temperatures, change precipitation patterns, cause more extreme weather, and acidify the oceans. Emissions abatement has been the leading policy response to climate risks, but there are reasons to believe that this will continue to be inadequate. For one thing, emissions abatement presents a global intergenerational collective action problem whose enactment requires each country to undertake locally costly actions in order to prevent future damage throughout the world—including in distant locations. Such steps are generally politically unpopular and the temptation to free-ride is great. Another reason is that countries greatly diverge in their interests in, and commitments to, abatement. Industrial countries are wealthy enough that their residents appear willing to pay—albeit to a limited degree—to reduce such future and distant environmental damage. In contrast, in developing countries, widespread access to reliable, affordable energy based on fossil sources remains the only known viable route to economic development with its concomitant improvements in living conditions. Understandably, residents and political leaders there insist on it. Thus, abatement measures that are affordable from the perspective of a wealthy country may pose unacceptably high opportunity costs for developing ones. Notably, the majority of current total GHG emissions, and the vast majority of future emissions, come from developing countries, further muddying the international political dynamic.

Given this bleak outlook, some scientists and others who are concerned about climate change have proposed intentional, large-scale interventions in earth systems in order to reduce climate change and its risks. These proposals for 'climate engineering' or 'geoengineering' often include two distinct categories: SCE, and 'carbon dioxide removal' (sometimes called 'negative emissions technologies'). There is a growing sense

that these are more productively considered separately, as they present distinct benefits, capacities, risks, limitations, costs, speeds, and uncertainties (Committee on Geoengineering Climate: Technical Evaluation and Discussion of Impacts 2015a; 2015b). Therefore, suggestions for carbon dioxide removal via methods such as direct air capture, bio-energy with carbon capture and storage, and ocean fertilization are not examined in this chapter.

As noted, SCE would slightly increase the planet's reflectivity in order to counter climate change. Two methods presently appear to have the most potential and receive the most attention. First, evidence from volcanoes and air pollution indicates that small airborne particles of some substances, such as sulphur dioxide, reflect incoming sunlight and consequently cool the planet. Some scientists have proposed that aerosols of this or other substances could be injected into the stratosphere—a layer of the upper atmosphere—in order for this cooling effect to be global. In the second widely-discussed proposed method, seawater sprayed as a fine mist into the lower atmosphere would, upon the drops' evaporation, leave behind small salt particles. In turn, these would function as cloud condensation nuclei, making clouds brighter. There are other ideas for SCE (Committee on Geoengineering Climate: Technical Evaluation and Discussion of Impacts 2015b), and the future may bring techniques quite different from those that we presently imagine.

Several characteristics of SCE are important for the purpose of this chapter. First, it appears that some methods would work, in the sense of being able to return global average temperature and precipitation (that is, rain- and snowfall) to levels close to preindustrial conditions. The Intergovernmental Panel on Climate Change concluded in its most recent Assessment Report that 'Models consistently suggest that SRM would generally reduce climate differences compared to a world with elevated greenhouse gas concentrations and no SRM' (Boucher and others 2013: 575).<sup>1</sup> Second, these proposals seem to be technically feasible. Third, SCE would have transboundary impacts. Stratospheric aerosol injection would be global in effect, although partial variation by latitude may be possible, whereas marine cloud brightening may have some degree of regional applicability. Fourth, SCE would be imperfect. It would reduce temperatures more near the equator, yet global warming will be most severe near the poles. Moreover, both climate change and SCE would change precipitation patterns, perhaps in unpredictable ways. In other words, in a world of elevated GHG concentrations and SCE, some regions would experience residual climatic anomalies of temperature and especially precipitation. There are other environmental risks. For example, sulphur dioxide is expected to contribute to the destruction of stratospheric ozone. The diffuse sunlight under SCE would increase plant productivity, resulting in improved agriculture and altered ecosystems. Fifth, SCE would be rapidly effective after implementation, and its

direct climate effects appear to be reversible on short timescales. In contrast, the desired results of emissions abatement are delayed. Sixth, these techniques are presently believed to have very low direct financial costs of implementation, on the order of tens of billions of US dollars annually. In climate economics, where the costs of damages and emissions abatement are given in trillions of dollars, this is a nearly insignificant amount. Finally, SCE's potential and risks remain to some degree uncertain and unknown, and the actual technologies are at very early stages of development. Some uncertainties can be reduced through modelling and experiments, but others are likely irreducible.

These characteristics lead to several opportunities and difficulties. SCE's apparent technical feasibility and low direct financial costs imply that many actors—state and perhaps even non-state—could implement it. In contrast to emissions abatement, for several countries the economic and environmental benefits from SCE's reduction of climate change appear to outweigh the expected implementation costs. Thus, this inverts the collective action problem and concomitant free-riders of emissions abatement into a single best effort problem with potential 'free-drivers,' i.e. actors who provide a public good but often in excessive quantities (Barrett 2008; Bodansky 2012; Weitzman 2015). The challenge is thus transformed from one of getting all states to do enough of something that is costly to each of them into one of preventing them from doing too much of something inexpensive. The latter problem of collective restraint has an easier structure to resolve (Barrett 2007; Bodansky 2012). At the same time, it is unclear how countries would decide whether, when, and how to implement SCE, and how they would settle potential disputes. This is even more difficult because they may have divergent preferences as to their ideal climate. Indeed, although scientists currently speak of using SCE to counter climate change, future political leaders may desire otherwise.

Likewise, the speed with which SCE could be effective and be reversed has both advantages and disadvantages. It could be implemented on a relatively short timescale if abatement and adaptation efforts remain insufficient, or if climate impacts are much greater than expected. Thus, its development could serve as a sort of insurance policy against climate change risks. In fact, given the delayed effects of emissions abatement, SCE is the only means to reduce climate risks in the short term. On the other hand, if SCE were to be implemented under conditions of greatly elevated GHG concentrations and then stopped for some reason, the climate change that had theretofore been suppressed would manifest rapidly, with severe impacts.<sup>2</sup>

Finally, the relationship between SCE and other responses to climate change risks is a highly contested matter of great salience. Indeed, the belief that its consideration, research, or development would undermine the already inadequate and fragile efforts to abate emissions has been the leading concern regarding SCE. Advocates of SCE research often envision it as complementing abatement, adaptation, and carbon dioxide removal,

with each approach filling different functions in a portfolio of responses to climate change. Of course, the incentives facing the decision makers of tomorrow will be different from those of today's researchers. These future politicians—with their short time horizons—might pursue SCE in socially suboptimal and normatively undesirable ways. Nevertheless, this common fear has gone mostly assumed yet inadequately examined as to whether emissions abatement would actually be reduced by considering SCE, whether this would cause net harm, and what regulation could do to prevent it (Parson 2013; Lin 2013; Reynolds 2015a).

### **3. Solar Climate Engineering as an Emerging Technology**

The contemporary discourse of technology, law, and regulation arguably grew and matured largely in response to anxieties and perceived regulatory gaps concerning new practices in the life sciences. Chief among these practices were genetically modified organisms and new human reproductive technologies. In recent years, synthetic biology, nanotechnology, information technology, robotics, and applied cognitive science have been added to the array of so-called 'emerging technologies' (see Allenby 2011).

In some ways, SCE fits this set. Technological developments can outpace law's ability to adapt (Bennett Moses 2016). Expertise—often from those who themselves develop the technologies and would be regulatory targets—is often needed in order to craft effective regulation. Yet this reliance on expertise also raises the risk of actual or perceived elite technocracy, which could potentially undermine regulatory legitimacy. Development and implementation of these technologies can pose both physical and social risks that may be of large scale, of great magnitude, and highly uncertain. These can take the form of risks to human health and safety, to the environment, to rights (see Goodwin 2016; Sartor 2016; Murphy 2016), to dignity (see Düwell 2016), to identity (see Baldwin 2016), to social structures and institutions (see Sorell and Guelke 2016), and to widely held values.

At the same time, SCE is somewhat incongruous with these 'traditional' emerging technologies in three key ways. Together, these differences imply that SCE may warrant a distinct approach to its regulation and law, or at the very least, should give rise to a dissimilar political landscape. First, the development of most other emerging technologies is driven by benefits that are (or are expected to be) captured by their producers and consumers, while their controversy arises from negative effects to third parties. For example, genetically modified crops may increase profits for the biotechnology companies that produce them and the farmers who use them, but they are

sometimes seen as posing risks to ecosystems, consumers, and other farmers. As noted in the previous paragraph, this harm need not be physical: advanced human reproductive technologies can give prospective parents a healthy child and enable the growth of a profitable assisted reproduction industry, but morally harm those people who hold dignitarian ethics. In other words, these emerging technologies can usually be framed as what economists call a negative externality. In contrast, those who are presently researching SCE—scientists in North America and Europe—appear to have little to gain directly and personally, relative to the stakes of climate change. Obviously, career advancement, greater income, fame, and personal satisfaction are possible and presumably desired. Yet assuming that SCE will function as is currently believed, public benefits would exceed private ones by several orders of magnitude, and most benefits would accrue to those in the regions that are especially vulnerable to climate change, such as sub-Saharan African and south Asia. This gap between private and public benefits would be particularly great in the absence of extensive and enforced intellectual property claims. Indeed, open publication of results and limitations on or full rejection of SCE patents is an emerging norm of SCE research (Bipartisan Policy Center’s Task Force on Climate Remediation 2011; Leinen 2011; Solar Radiation Management Governance Initiative 2011; Mulkern 2012; Rayner and others 2013; Reynolds, Contreras, and Sarnoff 2017). Under these circumstances, SCE would be a more public endeavour when compared to other emerging technologies.

Second, most emerging technologies have promised or offered new, additional benefits relative to the present. For example, robots could reduce the need for humans to perform dangerous work that the latter presently perform. On the other hand, SCE is intended to reduce the as-yet unfelt negative impacts of expected future changes. It would not offer benefits relative to today, but instead only may provide a ‘less bad’ tomorrow. In fact, relative to the present, most people find it generally unappealing. Although from a rational perspective this distinction between a positive and the prevention of a negative should not be relevant, people exhibit a preference for status quo, and baselines are subsequently important.

Third, as a consequence of the latter, or perhaps both, of the above, the rhetoric of the technologies’ proponents greatly differs. The drivers of ‘traditional’ emerging technologies, such as genetically modified crops and new human reproductive techniques, include a fair number of boosters, who exuberantly tout the wonderful benefits of their products. Meanwhile, supporters of SCE research are a rather dour lot. Some of the most prominent of them have said: ‘Only fools find joy in the prospect of climate engineering’ (Caldeira 2008) and ‘it is a healthy sign that a common first response to geoengineering is revulsion’ (Keith, Parson, and Morgan 2010: 427).

## 4. Political Dynamics

Yet, as with the ‘traditional’ emerging technologies, there is more at play in the growing climate engineering discourse than mere benefits and risks. SCE appears to hold the potential to greatly reduce climate change’s grave risks to vulnerable people and ecosystems, threats that cannot be prevented by any realistic level of emissions abatement and adaptation. Nevertheless, reactions to SCE have been very diverse, including visceral criticism by some of those who are most concerned about the environment. Here, I posit three reasons for this wide range of reactions. These three reasons are mutually consistent, and may simply be multiple ways of perceiving the same phenomenon.

The first suggested way to understand such a wide range of reactions lies at the intersection of psychology and culture. Climate change has become much more than mere environmental risks or market failure. It brings forth our underlying worldviews, reinforcing and shaping how we see ourselves, the groups to which we belong, society, and the natural world (Hulme 2009). The cultural theory of risk can provide a useful lens to help comprehend various worldviews (Thompson, Ellis, and Wildavsky 1990; Verweij and others 2006), organizing them on two axes (Figure 1). The horizontal axis concerns the value placed on solidarity of the social group. The vertical axis depicts the person’s sense of constraint from social rules and ranking. Positions along these two axes, sometimes called ‘group’ and ‘grid’ respectively, define general worldviews in the four resulting quadrants. Of these, the two that highly value groups’ solidarity (high group) generally emphasize the importance of socially organized action for environmental protection.<sup>3</sup> Indeed, these ‘hierarchists’ and ‘egalitarians’ are often able to cooperate, calling for GHG emissions abatement and adaptation (Leiserowitz 2006; see also Nisbet 2014). However, these two groups’ different senses of constraint from social rules lead to diverging perceptions of social relations and of nature. Consequently, their preferences of specifically how to address environmental problems differ, including starkly contrasting positions regarding SCE (Heyward and Rayner 2016; see also Kahan and others 2015). ‘Hierarchists’ (high group, high grid) consider individuals to be circumscribed by their role in society, and nature to be fairly robust if it is well managed. They will mostly be comfortable with the consideration of SCE. In contrast, ‘egalitarians’ (high group, low grid) see people (ideally) as members of horizontal networks of equals, and nature as fragile. They will generally reject SCE as dangerous meddling with a vulnerable natural world and as necessitating undesirable hierarchical social structures.





*Click to view larger*

*Figure 1.* The four worldviews of the cultural theory of risk (after Thompson and others, 1990; Verweij and others, 2006)

The second means of understanding focuses on diverse goals of climate policy. Those political actors who call for strong and early emissions abatement and adaptation include at least three primary groups: those whose first wish is to reduce climate change risks to people and to ecosystems, deeper green environmentalists who consider emissions abatement to have the major co-benefit (if not primary benefit) of reducing humanity's

footprint upon nature, and those to whom climate policies are means to challenge the dominant economic order and to redistribute wealth.<sup>4</sup> These three primary constituencies are neither exhaustive nor mutually exclusive, and motivations are often mixed or remain subconscious. Regardless, SCE may be able to reduce net climate risks, furthering the goals of the first group. In contrast, it would do nothing toward efforts to reduce intervention in the natural world and inequalities of power and wealth. In fact, given the fact that SCE threatens to divide a fragile political coalition operating in a contested setting, its consideration could undermine the efforts of the latter two groups.

The third and final proposed means to understand various reactions to SCE is historical. The contemporary environmental movement arose in the 1960s. It was a response to the recognition that we humans were failing to take into account all of our actions' impacts, particularly on the nonhuman world and on the future. This failure seemed most evident in large-scale and technological endeavors. The dominant reaction in environmentalism was a call for a less intrusive, more humble relationship with the natural world. In contrast, SCE would be more intrusive and—by most definitions—not humble. Notably, the gestational decades of the environmental movement were also a time of heightened anxieties concerning nuclear war, and the environmental and anti-nuclear movements share common roots.<sup>5</sup> Contemporary environmentalism has subsequently charted a path dominated by skepticism—and sometimes outright rejection—of proposals for technological interventions into nature, especially those that would be large-scale and

centralized, instead preferring decentralized and more ‘natural’ responses. This skepticism or hostility is evident in the rhetoric that condemns SCE as a ‘techno-fix’ (for example, Hulme 2014). The term is almost always left undefined, but what is implied is an indictment that SCE would be an unduly inexpensive and fast means to address merely climate change’s symptoms, not its causes, with an inappropriate bias toward the artificial and away from the natural (see Flatt 2016, especially subsection ‘Technology is Not ‘Natural’: Critiques from the Left’).<sup>6</sup> On the other hand, there has always been an undercurrent—one that is arguably growing—within environmentalism that views new technologies as essential to reducing our net impact on nature. This complex, intertwined relationship between environmentalism and technology is reflected in the contemporary SCE discourse.

## 5. Existing Law and Regulation

There is presently no law specific to SCE. Of course, SCE is developing in the context of applicable existing law, some of which is briefly reviewed here.<sup>7</sup> This interpretation is somewhat speculative, because future law specific or applicable to SCE may be implemented, because SCE will unfold in ways that are uncertain and perhaps presently unknown, and because judges, regulators, and other decision makers may interpret this body of law differently. Furthermore, existing law can appear to be contradictory when attempting to apply it to a domain for which it was not designed. Perhaps the greatest challenge in interpreting extant environmental law is that both SCE and climate change—which SCE is intended to counteract—each pose risks to humans and the environment. For example, in the international domain, SCE often satisfies the definition of ‘pollution’ or other phenomenon that the law was intended to reduce.<sup>8</sup> Because SCE would have transboundary, if not global, impacts, the summary here is limited to the most pertinent international law (see Rayfuse 2016).

As a starting point, state action (and inaction) is presumed to be permitted in the absence a violation of a particular legally binding international agreement or custom, provided that the state practices due diligence if there is a risk of significant transboundary harm arising from activities within its territory or under its jurisdiction. The customary due diligence includes appropriate measures to prevent or reduce potential harm; review by competent national authorities; prior environmental impact assessment; notification of, consultation with, and cooperation with the public and the countries likely to be affected; emergency plans; and ongoing monitoring.

The international agreement that appears to be most pertinent to SCE is the UNFCCC. After all, it is the leading climate treaty, with global participation. However, closer inspection reveals an ambiguous legal setting. Its objective is the ‘stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’ (UNFCCC: Art. 2) SCE could reduce climate risks without directly affecting GHG concentrations. However, it may indirectly reduce them by, for example, increasing terrestrial plant productivity (Keller and others 2014). This might justify including SCE within the scope of the UNFCCC. Regardless, some commitments and hortatory statements in the agreement implicitly favour at least the consideration of SCE, perhaps through research. For example, states commit to undertake research, and to develop and transfer technologies, related to climate change (UNFCCC 1992: Arts 4.3, 4.7, 4.8, 4.9 and 11.1). Furthermore, under the recent Paris Agreement of the UNFCCC, states commit to limit global warming to low levels that likely cannot be satisfied through emissions abatement alone. SCE could contribute to staying within these limits.

A more directly applicable (but less well known) treaty is the 1976 Environmental Modification Convention (ENMOD). It prohibits the hostile use of ‘environmental modification techniques ... having widespread, long-lasting or severe effects’ (ENMOD 1976: Art I). Although the term ‘environmental modification’ was intended to address weather modification, its definition clearly includes SCE (ENMOD 1976: Art II). The agreement explicitly does not impede environmental modification for peaceful purposes; in fact, it encourages their development (ENMOD 1976: Art. III). The Convention’s 77 current parties include most states with industrialized or emerging economies. However, it has no standing institutional support and its parties have met only twice, with a proposed third review conference rejected in 2013. ENMOD is thus considered dormant and poorly able to adapt to changing circumstances.

The Convention on Biological Diversity, agreed upon in 1992, is a multilateral environmental agreement whose broad scope, strong institutional support, and near-universal participation have led its parties to take interest in a wide variety of large-scale activities that pose environmental risks. In recent years, they have issued four statements on climate engineering. The most relevant one—and the only such statement from an international legal forum with such broad participation—is a nonbinding statement of caution, asking the Convention’s parties to refrain from climate engineering that may affect biodiversity until there is sufficient scientific basis and consideration of its risks, or until there is ‘science based, global, transparent and effective’ regulation (Conference of the Parties to the Convention on Biological Diversity 2010).

If a state’s actions were contrary to an international binding agreement or to customary law, then the *ex post* law of state responsibility would come into play. This calls for the

cessation of the activity; assurances of non-recurrence; reparations through restitution, compensation, and satisfaction; and victims' access to legal remedies. The matter of compensation and possible liability for harm from SCE is extremely complex both because of its widely distributed effects, and because of the difficulty in attributing specific weather events and climatic trends to a particular SCE activity (see Horton, Parker, and Keith 2015; Reynolds 2015b; Saxler, Siegfried, and Proelss 2015).

From this and more extensive reviews, it is clear that even though some extant international law is applicable to SCE, these provisions either have imprecise obligations (customary law), are of uncertain scope (UNFCCC 1992), pertain to limited circumstances (ENMOD 1976), have only indirect applicability (CBD), or govern particular geographic domains (UN Convention on the Law of the Sea of 10 December 1982). The result is a heterogeneous, fragmented patchwork of international law that contains numerous gaps and overlaps. Of course, an assessment of international law is not merely a matter of scope and applicability, but should also consider a wider array of indicators for the potential effective regulation of SCE (Armeni and Redgwell 2015).

## 6. Future Regulation

### 6.1 Regulatory Rationale

The previous section indicated that existing international law offers inadequate regulation of SCE. Before considering proposals for potential future regulation, we must first examine why SCE should be regulated in the first place, contrasting two general approaches for simplicity. More economically-oriented legal scholars such as Cass Sunstein (1993) and Richard Posner (2014) point toward various market failures as justifications, many of which can be applied to the SCE setting. For example, the generation of knowledge through research and the implementation of SCE—if it might offer net benefits—would be positive externalities that should be encouraged. The costs of carrying out these activities would represent a collective action problem, wherein those who would benefit may fail to contribute in the absence of law.<sup>9</sup> Likewise, harmful impacts from SCE field research or implementation would be negative externalities that should be reduced through regulation. Furthermore, different groups of people would have unequal ability to influence SCE decision making processes, even though they could all be affected. Policies to promote their inclusion and to minimize principal-agent problems would thus be warranted. Similarly, certain actors who could benefit from SCE policy would be tempted to influence it, a form of rent-seeking behaviour, which should

be discouraged through law. Widespread beliefs regarding SCE may not align with the best evidence, and information campaigns—a form of regulation—may then be appropriate. Finally, the coordination of SCE research and implementation by public bodies would be needed in order to maximize the efficiency of expenditures, to prevent SCE activities from interfering with each other, and to reduce conflicts.

In contrast, some writers such as Roger Brownsword (2008) and Tony Prosser (2010) also include more social rationales for regulation, such as the need to protect rights and to maintain solidarity. Here, a rights-based approach emphasizes that certain minimal standards for all persons (and potentially other rights holders) should be satisfied, and that these standards must not be sacrificed in the name of greater net social welfare.<sup>10</sup> In the international context, this implies that SCE regulation should strive to not violate—and perhaps even to further—fundamental human rights. A goal of maintaining social solidarity would call for SCE regulation to avoid undermining existing social relations that foster cohesive communities at multiple scales. Here, matters of preventing international tensions might come to the fore.

### 6.2 Challenges for Regulation

It is encouraging to observe the emergence of a diverse, thoughtful discourse regarding how SCE could and should be regulated well before any field experiments and (hopefully) even longer before any implementation has taken place. Nevertheless, the ‘what’ and ‘how’ of SCE regulation remain unclear. This is an example of the Collingridge Dilemma (Bennett Moses 2016). In this, technology regulators face a double bind, in which early on they know too little of a technology and its risks to effectively craft policy, yet once the technology is more familiar, then the social and economic costs of changing policy are great.

A particular challenge lies in defining the regulatory target, in terms of what behaviours are to be regulated. This can be considered along two imaginary dimensions. The ‘vertical’ one concerns the developmental stage or the scale at which SCE should be specially regulated. Global SCE implementation would represent a *sui generis* intervention into the environment, and there is essentially unanimity that it should be subject to some sort of legitimate, international, and preferably legal decision making process. Thus, one of the five influential Oxford Principles of climate engineering is ‘governance before deployment’ (Rayner and others 2013). It remains contested, however, whether SCE research should also be subject to particular regulation. If one were to adopt a strictly economic orientation, described above, then concerns specific to SCE begin to arise primarily with large-scale field trials that would alter the albedo (or more accurately stated, radiative forcing) at a magnitude that would pose risk of

significant harm to humans or ecosystems.<sup>11</sup> Here, one could propose a quantitative threshold of the intervention's magnitude (Parson and Keith 2013) or a qualitative definition akin to the 'widespread, long-lasting or severe effects' seen in ENMOD and elsewhere. However, some commentators have called for some form of governance even before any small-scale outdoor tests with negligible environmental impact (see Parker 2014). Yet this may place potentially unneeded but burdensome requirements on physically innocuous activities. Two researchers rhetorically illustrated this by asking: 'If I paint a one metre square with white paint on my dark asphalt driveway and measure the reflected sunlight, is that a field test of solar climate engineering?' (Caldeira and Ricke 2013).

The other, 'horizontal' dimension of defining the regulatory target is that of distinguishing SCE from similar activities. This is especially pertinent in the research domain. Let us assume that outdoor SCE research projects should be subject to some sort of particular governance beyond what is required for other scientific projects. Most definitions of SCE proposed thus far rely on intent, which is difficult to determine and demonstrate reliably. As the regulatory requirements increase, then researchers would face stronger incentives to portray their activities as something other than SCE. Yet removing intent from the definition poses a mirror image problem. That is, relying solely the physical nature of the research activity and its expected effects could impose additional regulatory burdens on too broad of a swath of scientific activities. This is particularly worrisome because the knowledge and research relevant to SCE and climate change often overlap. For example, consider that aerosols and clouds are key lingering uncertainties in understanding climate change. A recent research project injected small particles into the lower atmosphere above the ocean and monitored their impact on clouds (Russell and others 2013). Although this was (purportedly) to improve knowledge of climate change, it has implications for SCE, particularly marine cloud brightening. This is not to imply any specific motivation among the researchers, but only to demonstrate the gradual spectrum between SCE and non-SCE research activities and the resulting difficulty in balancing regulatory precision and effectiveness.

An example in the implementation domain highlights further difficulties with 'horizontally' delineating SCE activities. The leading candidate material for stratospheric aerosol injection—sulphur dioxide—is presently a hazardous pollutant in the lower atmosphere, and masks a sizeable portion of climate change (Boucher and others 2013). Anti-pollution policies have been reducing sulphur emission and the resulting atmospheric concentrations. (In fact, total global sulphur emissions appear to be peaking.) Although by an ordinary meaning these anti-pollution policies are not SCE activities, they will alter the climate by changing the earth's albedo. Somewhat akin to the above issue of researchers' intent, here the stated goal is the reduction of lower

atmospheric pollution, but climate modification is a predictable, foreseen consequence. Furthermore, the policies' effect will be to warm the planet, raising the question as to whether SCE regulation should be limited to efforts to counter global warming, or whether it should include all deliberate climatic alterations (Somsen 2016). A principle of technological neutrality in regulation supports the latter.

A final challenge when crafting regulation for SCE is legitimacy. This is not necessarily limited to SCE per se, but instead is largely due to the extant circumstances of climate change. As described above, the reduction of climate change risks through emissions abatement presents a global collective action problem. Overcoming this may call for some sort of global governance, an endeavour that itself faces legitimacy challenges (Buchanan and Keohane 2006). Thus, a prospective international agency deciding whether the global climate should be intentionally altered, or a scientific panel assessing the safety of intentional climatic interventions may not fundamentally differ from an international agency setting a price on carbon to keep global warming below a certain target, or a scientific panel assessing the safety of unintentional climatic interventions.

### 6.3 Proposals for Regulation

Therefore, international regulation of SCE is warranted, at least at some stage in the technologies' development, yet there presently are significant gaps. Much of the discourse concerning SCE within legal scholarship has considered potential regulatory regimes.<sup>12</sup> Some of their characteristics will be contrasted here, the first of which is authors' regulatory rationales. Most explicitly or implicitly emphasize minimizing uni- or mini-lateral action contrary to the desires of the international community as well as the negative environmental impacts of SCE implementation. The former is typically achieved through an international decision-making process that would aim to be legitimate. Many regulation proposals seek to maintain some degree of alignment between policy and public opinion, often via public deliberative or participatory processes. Other common desiderata include avoiding the reduction of emissions abatement, preventing a dangerous 'slippery slope' from research to implementation, minimizing the chance of abrupt termination of SCE, and compensating victims of negative environmental impacts. Some authors suggest means to promote responsible research by facilitating and coordinating it, by encouraging international collaboration, by requiring transparency, and by calling for independent assessment of results.

These diverse regulatory rationales imply a second manner in which proposals for SCE regulation vary: most focus on implementation, whereas some look also to its research. Similarly, although most speak only of an optimal endpoint, a minority of scholars describe potential next steps towards regulation in order to chart a policy path forward.

For example, some writers have produced a detailed code of conduct for climate engineering research that would begin to operationalize existing norms for climate engineering, such those seen in the Oxford Principles, in a manner consistent with international law (Hubert and Reichwein 2015).

A third variable is the ‘depth’ of commitment of suggested regulatory regimes. Some observers foresee states relinquishing their authority over SCE decision making to an international institution, whereas others are more modest and emphasize principles, best practices, information exchange, independent assessment, consultation, and other limited forms of cooperation. Related to this, the degree of legalization envisioned ranges from bottom-up cooperation among state and non-state actors to binding multilateral agreements. Finally, the proposals also differ in their projected ‘breadth’ of participation, from only those states with the capacity to implement SCE to all countries.

## 7. Uncertainty and Precaution

Managing uncertainty is a central challenge to law and regulation, and especially that for new and emerging technologies (Bennett Moses 2016). In the case of SCE, uncertainty is compounded because the technologies’ justification—climate change—itself remains highly uncertain. Specifically, there are wide-ranging estimates of GHG emissions pathways (which in turn are functions of *inter alia* population, economic activity, technological developments, politics, and law), of climate change’s magnitude per increase in GHG atmospheric concentrations, of damages per unit of climate change, and of societies’ and ecosystems’ adaptive capacities. SCE would be a set of additional uncertain factors, with its expected effects only now beginning to be systematically modelled.

A guiding principle for managing uncertainty in international environmental law, and in some specific national jurisdictions, is precaution, which arose in part as a response to new technologies’ uncertain risks. In the international domain, a principle such as precaution is not legally binding or enforceable on its own, but must instead be operationalized in a specific context, such as a multilateral agreement. For example, the UNFCCC reflects a common formulation of precaution:

The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account



that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost

(UNFCCC 1992: Art. 3.3).

How might SCE regulation be guided by precaution? At the very least, there is sufficient diversity in both SCE scenarios and in the formulations of the precautionary principle that the relationship between them is not simple (Tedsen and Homann 2013). Philosopher Lauren Hartzell-Nichols asserts that SCE is contrary to precaution because it might pose the risk of catastrophe, and because emissions abatement and adaptation are available as alternatives (Hartzell-Nichols 2012). This, though, requires an inflexible version of the precautionary principle that rejects all measures such as SCE that pose a risk of catastrophe but may prevent a more severe catastrophe. Instead, the language of the UNFCCC provides some guidance, at least in the short term: responsibly researching SCE would be a measure that may mitigate the adverse effects of climate change, and 'lack of full scientific certainty should not be used as a reason for postponing such measures' (UNFCCC 1992: Art 3). This is particularly the case, given the low projected costs of SCE and the high projected costs—as well as the unlikelihood—of preventing dangerous climate change through emissions abatement (see Reynolds and Fleurke 2013).

## 8. Future Directions

The scholarship on the law and regulation of SCE has grown to the point where it can be characterized as a genuine body of literature. Within a few years, writers have extensively considered some aspects, such as the role of international law and potential future regulation of SCE implementation, and began to address others, such as the potential for liability for harm. Here, I suggest a handful of important issues that remain underexplored. The first of these is the capacity for existing national and European law to regulate SCE (but see Hester 2011). It is true that if SCE is developed, then regulation would ultimately need to be international. However, national and European law are more detailed, better enforced, and more adaptable than international law, and the risk and impacts of field trials will most likely be international before they are transboundary. In addition, the law of subnational units, such as US states, should not be overlooked.

Second, the relationship between rights and SCE remains unclear. Above, I offered initial thoughts as to how rights might provide a regulatory rationale. This warrants exploration, particularly regarding how SCE can be understood within a human rights framework. If climate change threatens human rights, and SCE may be able to prevent its worst

impacts, then could a human right to SCE research or implementation be derived? Or conversely, is there a right to an environment that is free of manipulation by others?

Third, the possible roles of developing countries with respect to SCE must be researched and, where possible, clarified. Until now, the consideration of SCE has originated almost entirely from industrialized countries. Because these countries are responsible for the majority of historical GHG emissions, some observers implicitly or explicitly see potential SCE implementation as motivated by these powerful states' desires to avoid emissions abatement. Yet, if developing countries are at greater risk from climate change, then they may become drivers of SCE research and development. For example, Scott Barrett asserts that India is a likely candidate for implementing SCE unilaterally (Barrett 2014). A scenario in which small island states use threats of SCE implementation as a lever in international climate negotiations also seems feasible. What are the implications for SCE law and regulation of 'common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances' with respect to states' commitments to reduce climate change risks (UNFCCC 1992: Art 4.1)?

Fourth, in recent years, scholars of technology law and regulation have taken interest in not only the regulation *of* technology, but also regulation *by* technology. SCE could operate as such a regulating technology. In particular, its potential development and implementation could shape emissions abatement and adaptation policies and actions by, for example, providing a 'low cost backstop' to these actions or by serving as a threat, encouraging abatement and adaptation (Reynolds 2015a).

Finally, the literature on SCE has largely assumed that it would be used only to reduce climate change risks. However, there is no reason to assume that this would always be case. States and other actors might use SCE technologies to alter the climate to suit human desires. Moreover, some proposed SCE methods may have non-climatic purposes, such as weakening hurricanes, that could improve human well-being. Future environmental law could acknowledge, anticipate, integrate, and even centre upon environmental enhancement (Somsen 2016). Such a reorientation may occur sooner than expected.

## 9. Conclusion

The prospect of deliberately altering the global climate in order to counter the risks of climate change recalls a classic exchange of papers beginning with Martin Krieger's 'What's Wrong with Plastic Trees?' (Krieger 1973). There, he noted that 'the demand for rare environments is a learned one', and asserted that, 'If the forgery provides us with

the same kind of experience we might have had with the original, except that we know it is a forgery, then we are snobbish to demand the original' (Krieger 1973: 451, 450). Are reservations about SCE, in the face of climate risks, a sort of snobbery? This is striking, given that the vast majority of SCE critics (as well as proponents) are from countries that are not at the greatest risks from climate change.

The response by legal scholar Laurence Tribe, 'Ways not to Think about Plastic Trees', is a founding essay of contemporary environmental law, and is remembered for arguing that environmental law should incorporate non-anthropocentric values of nature (Tribe 1974). The core of his objection to substituting artificial environments for natural ones—even if this reflects people's desires—was that the new environments will shape the preferences of current and future generations. Ultimately, Tribe charted a moderate path, arguing that the necessary synthesis of the 'ideals of immanence with those of transcendence [should] embody a sense of reverence for whatever stands beyond human manipulation and its willed consequences, as well as a stance of criticism toward all that is given and a commitment to the conscious improvement of the world' (Tribe 1974: 1340). Among his cited shortcomings of relying solely on anthropocentric values is the probable 'fluidity' of means and ends. In the context of the article, his concern was that that artificial environments as a means to people's desired ends would subsequently reshape those ends.

More than forty years later, we may have witnessed a similar fluidity with regard to responses to climate change, albeit with the role of artificial and natural reversed. Those who are most concerned about climate change have struggled for a quarter century, usually in a defensive posture, advocating for emissions abatement as *the* means to reduce climate risks, and have found only limited—and insufficient—success. This may have caused them to experience means-ends fluidity. After all, in circumstances such as these, the means (emissions abatement) and the ends (presumably reducing climate change risks) seem to be highly congruous, if not synonymous. The prospect of SCE forces us to reconsider the actual goals of climate policy, and environmental law more generally. From my perspective, this is a welcome development.

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## **Notes:**

(<sup>1</sup>) More specifically, recent modelling indicates that SCE could counter the vast majority of climate change's expected temperature and precipitation anomalies at the regional scale (Kravitz and others, 2014).

(<sup>2</sup>) Note that the probability of a scenario in which (i) SCE is implemented at a great intensity, (ii) it is terminated, (iii) no other actor can assume its implementation, and (iv) humanity does not have more pressing problems than climate change is uncertain, and perhaps quite low. See Reynolds, Parker and Irvine 2016.

(<sup>3</sup>) The others are individualists (low group, high grid), who see nature as resilient, and fatalists (low group, high grid), who consider it to be ephemeral and generally do not engage in political discourses. These two worldviews are thus sceptical of or uninterested in action to reduce climate change risks.

(<sup>4</sup>) Effective international emissions abatement and adaptation policies would result in large transfers of wealth from rich countries to poor.

(<sup>5</sup>) *Silent Spring*, for example, was the 'Book of the Month' in the US during the Cuban missile crisis. See also Rothman 1998.

(<sup>6</sup>) The utility of the term 'techno-fix' is even less clear than its definition (Scott 2012). Note that the term 'technological fix' arose in the era of high modernism as a positive descriptor of a technology that can address a problem that is intractable to social responses (Weinberg 1966).

(<sup>7</sup>) For a more thorough treatment, see Bodle and others 2014; Reynolds 2017.

(<sup>8</sup>) Consider this definition of pollution (with minor variation) found in several environmental agreements, such as the UN Convention on the Law of the Sea (Art. 1.1.4) and the Convention on Long-Range Transboundary Air Pollution (Art. 1), as well as in other international legal documents: 'pollution means the introduction by man, directly or indirectly, of substances or energy into the environment resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems, and impair or interfere with amenities and other legitimate uses of the environment.'

(<sup>9</sup>) As described above, the expected costs of SCE implementation are low enough, and the expected benefits great enough, that free riding would probably not be a problem in the international arena. Yet research and implementation costs would still need to be met. Moreover, SCE activities may present a nonpecuniary collective action problem. If SCE research (or even implementation) were unpopular among leaders' constituents but expected by experts to be potential, then decision makers might need some form of international cooperation so that they each would contribute the necessary political capital.

(<sup>10</sup>) Without engaging in debates unsuited for this chapter, this is compatible with an economic approach through considerations of welfare distribution based upon equity weighting.

(<sup>11</sup>) Other rationales from an economic perspective for regulation of SCE may arise at an earlier stage, such as the need to publicly fund and coordinate research. However, these are not particular to SCE.

(<sup>12</sup>) See Barrett 2008; Victor 2008; Lin 2009; Virgoe 2009; Benedick 2011; Redgwell 2011; Abelkop and Carlson 2013; Bodansky 2013; Dilling and Hauser 2013; Hester 2013; Honegger, Sugathapala, and Michaelowa 2013; Kuokkanen and Yamineva 2013; Parson and Ernst 2013; Scott 2013; Zürn and Schäfer 2013; Barrett 2014; Bodle and others 2014; Reynolds 2014; Reynolds 2015b; Chavez 2016; Larson 2016; Lin 2016.

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