Solar Radiation Management and the Governance of Hubris

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ABSTRACT

Proposals for the intentional engineering of the Earth's climate through techniques of solar radiation management (SRM) have been accompanied by profound questions of governance. As the purpose, goals and motivations of SRM are considerations of paramount importance, governance must not only encompass risks and unintended consequences, but also intent. In this chapter, I pose two questions as these relate to SRM and governance. Firstly, should we be entertaining the thought of research or deployment of SRM and its governance, *i.e.* is SRM a legitimate object of governance, and if so under what conditions? And, linked to this, secondly, is SRM governable, particularly within democratic political systems? Arguing that SRM is a political artefact I will describe some potential problems it may present for democratic governance. I will go on to sketch a brief history of governance discussions and initiatives concerning SRM. In doing so I will observe that the boundary work of learned societies, some academics and others has attempted to legitimise SRM research as an object of governance, defining governance contours and thresholds, underpinned by normative principles. I will review some recent personal experiences of the first attempt to move from words to actions, in terms of governing a SRM research project within a framework for responsible innovation. I will finally review the results of emerging public and stakeholder dialogue exercises which reveal that while attitudes towards SRM research are nuanced and ambivalent, publics and many

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stakeholders have great antipathy, even hostility, towards SRM deployment. As research is projected through to deployment both become simultaneously framed and the legitimacy of SRM research questioned. Conditions for acceptable deployment that include the need for international agreement and governance may be perceived as being highly implausible, with concerns that SRM may prove incompatible with governance based on democratic principles, and may generate unprecedented forms of geopolitical conflict. Given these considerations I will conclude that the question of whether SRM, and its research, is a legitimate object of governance remains to be democratically decided, if indeed it ever can be.

Let us go then, you and I,
When the evening is spread out against the sky
Like a patient etherised upon a table;

T.S. Eliot

1 Introduction: Hubris, Piety and the Limits of Human Governance

In the *Historia Anglorum* (or the History of the English People) the medieval chronicler Henry of Huntington recounts the legend of how Cnut, the 11th Century King of Norway, Denmark and England, had his chair carried to the English sea shore, where he commanded the tide to halt. As the tide continued to rise 'without respect to his royal person' he leapt from the chair declaring

> *'Let all the world know that the power of kings is empty and worthless and there is no King worthy of the name save Him by whose will heaven and earth and sea obey eternal laws'.*

Cnut's actions, often misrepresented as hubris, were in fact a demonstration of piety. In his world the eternal laws of nature were beyond the will of Kings and mortal men: they were only governable by God. The medieval, deontological society of Cnut has all but disappeared, although many still believe in this divine corporation view and the limits of human governance, royal or otherwise. Others of an atheist or agnostic persuasion may also recognise such limits, instead taking the position that there are some things that are *not governable at all*: by humans, Kings or God. They may acknowledge that there are some things (*e.g.* laws of chemistry, physics and such like) that we may be able to understand and use to our advantage (and which we have indeed used to change our environment, sometimes on a spectacular scale). There are other things we may be able to predict such as volcanic eruptions, but over which we have no control. And there are still other things, such as earthquakes, that we can neither predict nor control.

Those who have ever been at sea in even the most modest of storms, or in the path of a tornado, hurricane, or tsunami, will need no reminder of the power of nature, the fragile relationship we have with it, our own vulnerability, finitude and the limits of human control. In the face of those things that are ungovernable by man, if one is not inclined to be pious then there is at least a place for humility.

There is however another constituency of thought emerging, one that has arguably evolved from our history: this, at least in the West, first asserted that it is God's will that man exploit nature for his proper ends and subsequently, through the Enlightenment,[1] Ascent of Science (and its fusion with technology) and the Industrial Revolution, grew to conceive nature as a set of laws and processes that can be observed, learned, harnessed and controlled.[2] In the spirit of a modern day Prometheus, this world view perceives the limits of human ambition and its governance as being set only by ourselves. It perceives science and innovation as an endless frontier where nothing, including nature, is beyond human understanding, use and control, if only we put our minds to it; a Baconian relationship with nature defined in terms of mastery and even domination.[1,3] It is this hubris, and aspirations to govern it, that this chapter is concerned with. I will be discussing the governance of research and (possible) deployment of techniques known collectively as solar radiation management (hereafter which I will refer to as SRM). Robock (see Chapter 7) provides a detailed technical description of such techniques and associated potential effects, which I will not repeat here. The proposition is itself rather simple (and perhaps it might be argued rather elegant) and the technologies involved might even be described as being rather mundane, albeit deployed at a grand scale[4]: by increasing albedo, or the Earths ability to reflect back a small proportion of incoming solar radiation (or insolation), we might be able to induce a cooling effect, reducing global warming, by up to several degrees and in a relatively short timescale, perhaps a matter of years or even months. Proposals to modify the weather are hardly new, dating back at least to the 1830s when American meteorologist James Pollard Espy proposed controlled forest burning as a means to stimulate rain.[5,6] The context in which discussions concerning the research and possible use of SRM techniques are currently occurring is rather different. This is one of runaway rises in atmospheric CO_2 (arguably at least to some degree of our own making), the threats of this in terms of greenhouse gas-induced climate change and the potential to exceed so called climate 'tipping points'.[7] This is compounded by our inability, or unwillingness, to curb global CO_2 emissions, and the sad realisation that even if we did, the latency of atmospheric carbon means CO_2 levels will inevitably continue to rise.[7]

At its core is the idea that the relationship between our species and our planet is reaching, or has reached, crisis point, where SRM may present the only option left,[2] or the lesser of evils (see Scott, 2012 and references within for a broader discussion of this point in the more general context of environmental ethics).[8,9] This thinking argues that we should consider, and even have a moral duty to fund and undertake, research aimed at exploring the feasibility of engineering our global climate, perhaps at a planetary scale. Of the potential SRM techniques available two have been identified as particularly promising, on grounds of potential effectiveness, technical feasibility and cost[7,10]: cloud whitening (*e.g.* by increasing the number of cloud condensation nuclei in marine stratus clouds which form over substantial portions of the oceans *e.g.* using fine sea salt particles; and stratospheric particle injection (see Salter, Chapter 6),[11] whereby sub micron particles (*e.g.* sulfate aerosols) might be deliberately injected into the stratosphere (*e.g.* at approximately 20 km altitude and at a rate of several Tg S per year, (see Robock, Chapter 7) *via* a number of potential delivery mechanisms. The latter could, it is argued, allow us to mimic the atmospheric temperature reducing effects witnessed during large scale volcanic eruptions such as Mount Pinatubu in 1991 in which a transient global temperature drop of 0.5 °C was observed over several months. Cost, it would appear, is unlikely to be a limiting factor (see Robock, Chapter 7). It is, could, as some have stated, be cheap, fast and imperfect.[12]

It is these two forms of SRM that I will focus on. There is a great deal of uncertainty and ignorance regarding the technical feasibility, impacts and risks of such techniques. However what is clear is that such forms of SRM are aimed at alleviating the symptoms of lifestyle-associated disease in *Homo anthropocenus*, rather than providing a cure. Rather than addressing our obsession with growth and consumption and its associated high carbon lifestyle (in particular in the developed world and compounded by exponential population growth, especially in the developing world) – *i.e.* rather than addressing the causes of the problem, which are both moral and political in nature – SRM would serve only to treat some of its symptoms, while offering the potential to introduce uncertain and unevenly distributed side effects. These might include regional impacts, for example on precipitation, hydrological cycles (including possibly significant effects on tropical monsoons), polar ozone, and feedback effects which could counteract or reinforce those associated with climate change itself and which would be differentially distributed. Such symptomatic treatment would not constitute a one-off course: it would require periodic, or even continuous and possibly intergenerational administration.[7] It would require a delicate balance to be struck between reduced insolation and continuing greenhouse warming, perhaps for centuries. Sudden cessation of SRM could result in rapid temperature and precipitation rises at 5 to 10 times the rates of gradual warming (see Chapter 7),[12] and the effects associated with proposed cessation would then have to be balanced against those of continued use.

Critically, it seems clear that deployment would not ameliorate some effects of greenhouse gas accumulation (*e.g.* ocean acidification) nor return us automatically to some previous, desirable or steady climatic state. It would create a *new climate*, one which might benefit some, might not benefit others, may harm others still and may also harm many if we chose, or had to stop it. It could pose serious moral issues of restitution and intergenerational justice, *i.e.* as a new climate it might deny future people choices and opportunities they might otherwise have had, with little opportunity to opt out or go back.[3] Deployment would constitute an endless experiment with nature, and the societies that inhabit it.[4] Arguably we have been unintentionally changing our climate for some time, at least since the industrial revolution, but this would be different: it would be *intended*,[10] an important moral distinction.[3] And while all forms of life modify their contexts to some degree,[1] SRM would, properly, constitute *an end of nature* where global systems would be essentially linked to human choices,[2] managed and controlled by us at an unprecedented scale, the ultimate embodiment of Han Jonas' diagnosis of the altered nature of human action, mediated by technology.[13]

What counts as SRM research may not be readily apparent. Some SRM research might for example look rather similar to other climate related research, and *vice versa*: the difference may only be the intentions of the researcher(s) (see Heyward,[14] and Boucher *et al.*,[15] for further discussion on this point).[10] We must therefore talk primarily about the *governance of intent*,[16] rather than the *post hoc* governance of unintended consequences as these relate to our environment, of which we have some experience to draw on (*e.g.* chlorofluorocarbons (CFCs) and their impact on the polar ozone layer,[17] and the intercontinental transport and impacts of persistent organic pollutants such as organohalogens: there is plenty written on these subjects). These issues of motive, purpose and intent are critically important and can become matters of great concern among the public,[18] particularly in contentious areas of new technology such as genetic modification.

I would like to suggest there are two key questions relevant to governance as this relates to the research and use of SRM to engineer the climate. The first question is primarily an ethical one, a question of *should*. Is the intention to make a new climate using SRM *the right thing to do*, and is it something we should even be thinking about researching and attempting to govern? In other words, should SRM be, on normative and ethical grounds, *an object of governance,* and if so *under what conditions*?[3] There are at least two answers to this question: we should not entertain the thought of SRM research or application and the development of processes to govern this, *i.e.* SRM and its research are not a legitimate object of governance. We might collectively decide on a moratorium, or even a ban – which somewhat ironically might necessitate governance itself, albeit narrowly framed as ensuring, preventing or deterring SRM activity (*e.g.* research, field trials, deployment), if this were indeed possible. Or we might answer yes, SRM deployment and/or research constitute a legitimate object of governance, outright or with certain conditions – which begs the question what conditions would be applied,[3,4,19] and how could we ensure these are democratically arrived at.[8,18,20]

There are no specific regulations relating to SRM.[7] There are more general conventions relating to transboundary harm caused by *e.g.* atmospheric pollutants which could potentially encompass SRM, although enforceability would be an outstanding question. An agreement to prohibit large scale geoengineering under the UN Convention on Biodiversity was for example reached in 2010, but this is not legally binding, with few compliance structures and limited remit (see Olson, 2011, p. 38).[21]

I am going to argue that even so, what might be described as forms of *de facto* governance, and in particular the *boundary work* of experts (*e.g.* through their visions and judgements) and learned societies (*e.g.* through their reports), has attempted to legitimise SRM research as an object of governance, specifying certain normative principles and thresholds.[†] This boundary work has begun to identify the contours of, and conditions for, such governance, which I will describe. In doing so it has drawn a distinction between research (and within this certain thresholds of research) and use, a moral division of labour between science and application, which may have important consequences (such as the technological lock described in ref. 22). The question of whether this attempted legitimation is *democratic* remains, I suggest, open: it is as I will go on to describe, certainly contested. Despite this, SRM research (of many different kinds it must be stressed, including to some small degree social and political) *is* underway, with normative principles being declared under which it should be conducted and practical attempts at governance being experimented with, including attempts of my own with others, that I will later describe.

The second question is linked to the first, and is a '*can*' question. It asks whether SRM can be (practically, feasibly) governable and if so, how. SRM could certainly pose significant challenges for governance (see Box 1).

Clearly if one feels SRM is not practically governable, particularly using the institutions present in and between countries based on principles of democracy, then it is hard to argue for SRM as a legitimate object of governance. In fact both questions are profoundly Cnutian in nature, in that they challenge us to ask *whether SRM is, and should be, beyond the governance of man.* We all, collectively, find ourselves seated at the edge of the shore in this regard. They are not simple questions, and embed a raft of issues, from considerations of risk and uncertainty, to the status of knowledge, to issues of equity, power, intergenerational justice, values and, not least, our relationship with and place in the natural world. Those of a pious nature, those who feel SRM lies beyond the limits of human governance, may be inclined to jump up from the chair and be done with it. Those of a more hubristic disposition may be inclined to remain seated and try to find a way to metaphorically govern the waves, or rather skies, exploring what governance of SRM research, and even application, might look like: I will certainly attempt to provide some insights into the former that are emerging from the literature. For those of you who remain unsure, I will leave you to ponder your own position for now, and in fairness there is some detail that should be described and which may inform your position (not that this is my goal).

[†]The fact that this chapter, and others in this book, may also contribute to such boundary work is not lost on me.

Box 1 A few governance challenges for SRM.
(Adapted from Ref. 10, 4 and Robock, Chapter 7).

- How can international agreement over the 'ideal' global climate be reached?
- Who should decide, and on the basis of what criteria, where and when SRM field experiments and deployment should occur? Is it possible to come to such a decision democratically?
- Can legitimate, collective and democratic control over SRM deployment that some might seek to do unilaterally be established?
- Will SRM catalyse or require autocratic forms of governance?
- Can governance processes be developed, evolved and accommodated within existing democratic governance structures, including legal constructs, on a national and international scale?
- Could SRM lead to transferring risk to the poorest countries and the most vulnerable people?
- How would liability and compensation for adverse impacts, including on a trans-national and intergenerational scale, be handled? How would contested views concerning complex attribution of weather events to natural variation or SRM be handled and resolved?
- Can, and should, intent and motivation for SRM, which will always be plural, ever be governed, and if so how and by whom, at to what ends?

The remainder of the chapter is laid out as follows. I will first review in a rather general, and it has to be said sometimes speculative way, some features of SRM (as we know it) and how these may relate to governance. SRM has a vocabulary that includes ignorance, uncertainty, ambiguity and contingency. I hope then that these features will be treated as issues for consideration, rather than immutable facts. There is a small but growing literature in terms of SRM and its governance and no end of speculation to draw on. There is also a rich *corpus* of knowledge in terms of the social and political constitution, and governance, of technologies which serve as important heuristics, foundations and signposts for this, one of its most hubristic examples. I will then describe how SRM has been subject to various forms of *de facto* governance which have collectively attempted to legitimise its research as an object of governance, a process which has and continues to be highly contested.[4,23] In doing so I will also attempt to address the second question, *i.e.* is SRM and its research governable and if so how, including some of my own experiences. I will finally consider some illuminating, and rather ominous, recent work which has considered broader views (*e.g.* of publics) and their thoughts on SRM and its governance, which are highly germane to both questions.

2 SRM as Political Artefact

Governance of SRM can be defined in a number of ways. The Solar Radiation Management Governance Initiative (SRMGI) report that I will go on to describe refers to it as 'resources, information, expertise, and methods needed for the control of an activity, in order to advance the potential societal benefits provided by SRM, while managing associated risks'.[10] I find this to be a somewhat narrow and possibly instrumentalised framing in that the advancement of SRM and its benefits may appear implicit if we can manage risks, but it conveys the notion of a network of actors who exert influence over the direction, trajectory and conduct of SRM research and make decisions concerning its deployment. Governance can have different functions and operate at a number of different levels from regulation of many different types,[24–26] through voluntary codes of conduct (*e.g.* the European Commission Code of Conduct for Responsible Nanotechnologies Research,)[27] to governance by market choice. It can be prefixed by a number of words – innovation, political, democratic – all of which are relevant to SRM, and indeed many other emerging technologies. The word 'democratic' is an important adjective. Democracy in this regard can be considered as a 'heterogeneous set of subnational, national and supra-national practices, principles and institutions that serve to constitute citizens as part of a collectivity, able to act freely and equally, either directly or through elected representatives, in the practice of political self-determination'.[28] Such practices, principles and institutions include: political pluralism; free and fair elections; equality before the law; protection of civil liberties; freedom of speech; sovereignty of national governments; ability to get redress for harm through legal systems; a minimal level of human rights; and a functioning of civil society.

It may at first appear simpler to identify technological solutions (a 'technofix') than it is to resolve moral and political problems,[9] until one realises that technological solutions themselves can be morally and politically constituted, and morally and politically entangled. It is well known that governance, power and technologies are interlinked, that technologies are socially constructed and that they embed political dimensions.[29] I am not going to review the social constructivist literature concerning technologies here, but suffice to say that it shows that technological things are social and political, as well as technical in nature.[18,30] This social and political aspect of their being can be emergent, often in an unpredictable way, in which unintended impacts of some type *must be expected to occur*. Technologies can also be selected, socially constructed and purposed/re-purposed with the intention of producing particular economic, social and political consequences, of which dual use of technologies (*e.g.* for military and terrorist purposes) is just one obvious example. Technologies can also be made political by design: the incorporation and embedding of certain values (social and political) into design is well known.[31,32] In other words, as Langdon Winner famously stated, 'artefacts can have politics.'[29] The objective of SRM to increase planetary albedo is as much a political project as it is a technical one. But this is not a stable political artefact: it is and will be associated with instability, dynamism and plurality in terms of its framing and goals (see Robock, Chapter 7). These goals might include: addressing threats to food or water supply; environmental objectives (*e.g.* to protect vulnerable polar regions and stem the loss of Arctic sea ice, to stop sea level rise); or goals (possibly simultaneous) that are humanitarian, commercial or military (see SRMGI, Box 2.1,[10] and Bipartisan Policy Center Task Force on Climate Remediation Research).[33] They may belie a range of motivations which are unlikely to exclude those of a political and commercial nature.[10] The goals of, and motivations for SRM are far from clear, or agreed (see Robock, Chapter 7). There is considerable opportunity for SRM to become conditioned, and even stabilised by powerful economic and political interests, and not just those in opposition to carbon mitigation measures, in particular if there are considerable commercial or political gains to be made. Intent will be *interpretively flexible* (this is not uncommon for new technologies) and challenging to govern. The governance of purpose and motivations *via* Hayekian principles of revealed consent through market choice may neither be possible, nor desirable.[26]

Technologies can not only catalyse or be selected to advance or hinder particular forms of politics, but, as Winner[29] went on to describe, they may be (in)compatible with, or *require particular forms of political governance*. They can be 'unavoidably linked to particular institutionalised patterns of power and authority' (see also Joerges for further discussion).[34] It is prescient to ask what forms of political governance could SRM be (in)compatible with, or even require? The inability to reach global agreement on climate change mitigation, and in particular carbon emissions reductions, has put democratic processes under significant strain, and some might argue has constituted a failure of democratic governance.[8,28] At the very least it suggests that political institutions quite possibly lack the capacity to govern the development and deployment of SRM[10] SRM could in fact pose serious challenges for the processes and institutions of liberal democracy. The production of novel climate configurations might for example raise complex issues of justice and compensation. The natural and anthropogenic (SRM) origins for observed impacts on, for example, weather systems, wind speeds and ocean currents might easily become conflated, with cause and effect hard to attribute. Rayner *et al.* (2013) provide a hypothetic example whereby any unusual weather event (for example, something similar to the Pakistan floods of 2011) that occurred during the execution of a large scale field test might be blamed on such a test.[35] This would place strain on legal constructs of accountability, liability and compensation. It would inevitably lead to contestation, and may also cause conflict at national, regional or global scales, for example if SRM were pursued unilaterally by countries or wealthy institutions/individuals.[12] The potential for this, combined with the instability and plurality of framings and motives, may necessitate closed forms of decision making and forms of centralised, autocratic governance incompatible with the principles of democracy, in which a democratised world might ironically and tragically survive its own implications only through the dismantling of democracy itself: what Szerszynski *et al.* describe as a 'centralised, autocratic, command-and-control world-governing structure'.[28] They question the very notion that SRM is a legitimate candidate for democratic governance. The counter argument to this (and one that has been levelled at Winner's theories) is one based on contingency and the dangers of speculative ethics *e.g.* given the unpredictability of technologies, how can we be sure this autocratic constitution will be needed or indeed emerge, and surely if this is an undesirable outcome then, to echo David Collingridge's aspiration for corrigibility, can we not steward SRM towards democratic governance? Perhaps: I believe this at least to be a fair counter argument. And there are others (*e.g.* Kruger)[36] who contend that universal democracy is not a prerequisite for SRM but that engagement with representatives of countries which may be affected by it should be 'sincere, thorough and transparent'; he does not stipulate that those representatives should be democratically elected.

There are three summary points that emerge from the above discussion: firstly that SRM is likely to be a technology (or technologies) that are inherently political in the sense of being favourable to certain patterns of social relations and unfavourable to others; secondly that as a result there is 'an urgent need to make explicit the particular way in which SRM is being constituted as a technology, to interrogate the embedded assumptions and socio-political implications of this constitution, to question whether it might encourage forms of politics that may be incompatible with democratic governance, and to explore the specific challenges that SRM might pose to democracy itself'[28]; and finally, that the possibility that SRM has the potential to generate geo-political conflict and require (even instigate) autocratic forms of governance is a possibility not to be ignored. These are central considerations for the governance of SRM in democratic societies.

3 SRM Research and Attempts to Legitimate it as an Object of Governance

3.1 The Royal Society 2009 Report

I have so far presented SRM as an emerging technology defined by purpose(s) which may be co-opted for different goals and with different underlying motives (including political ones), and be (in)compatible with, or even require certain forms of political governance. It is a political artefact. I have described some emergent views as to why SRM may prove problematic in the context of democratic governance. I have characterised SRM as being interpretively flexible and unstable in terms of its framing and motives (see Selin, and references within for further, more general reading in this area).[37] In reality, these aspects of SRM and its governance have been only little explored to date.

It is naive to equate governance solely with regulation or legally binding conventions, of which I have already stated there are none specific for SRM. Governance can take many forms,[25,26] some of which may be as important as regulation, particularly in the context of new technologies. Of these, various forms of *de facto* governance,[38] sometimes overt, sometimes tacit, sometimes covert, are important in terms of framing technologies, and influencing their directions, trajectories and pace. In the case of SRM, the visioning and boundary work performed by key 'enactors' (who may represent a spectrum from strong advocacy to vehement detraction) – scientists, social scientists, funders, learned societies, journalists, activists for example – has been critical in terms of framing SRM and has included attempts to legitimise SRM research as an object of governance.

Of these, arguably one of the more significant pieces of boundary work was the report *Geoengineering the Climate, Science, Governance and Uncertainty* by the UK Royal Society in 2009.[7] It is evident from the title of this report that governance was a key consideration. The Foreword to reports such as these can be as important as their content. In the report Lord Rees, then President of the Royal Society, framed geoengineering as follows:

> *'nothing should divert us from the main priority of reducing global greenhouse gas emissions. But if such reductions achieve too little, too late, there will surely be pressure to consider a 'plan B' – to seek ways to counteract the climatic effects of greenhouse gas emissions by 'geoengineering'...the Royal Society aims to provide an authoritative and balanced assessment of the main geoengineering options. Far more detailed study would be needed before any method could even be seriously considered for deployment on the requisite international scale.'*[7]

The report aimed to clarify scientific and technical aspects of geoengineering, and contribute to debates on climate policy. It attempted to be inclusive in its evidence gathering, including some consultation and dialogue with the public. It is important to note that it considered geoengineering in its broadest sense, *i.e.* both carbon capture and SRM approaches, clearly distinguishing between the two. The Foreword was also clear about framing – as an option of last resort that should not serve to distract us from the priority of emissions reductions, but an option that should be properly researched. Since SRM might be the only option for limiting or reducing global temperatures rapidly it should, the report argued, be the subject of further scientific investigation in the event that such interventions become urgent and necessary.[7] This would serve to 'arm the future' with knowledge and additional options for managing the climate whilst continuing with mitigation efforts.[8] The report would be a balanced, authoritative assessment by experts which attempted to legitimise, and even authorise, SRM research and its governance, beginning to define research thresholds *e.g.* between laboratory and small field trials on one hand and large scale (*e.g.* transboundary) field trials and use on the other, which would subsequently become an important narrative. It catalysed the funding of research in the area of SRM in the UK, as I will later describe.

In a similar vein, in 2011 the US Bipartisan Policy Center's report on climate remediation recommended that the US Federal Government should embark upon a focussed and systematic research programme, arguing that if the climate system were to reach a climate tipping point and swift remedial action were needed then the US government would need to be in a position to judge whether geoengineering techniques could offer a meaningful response.[33] This research should develop capabilities and assess effectiveness and risks, to include field research as well as modelling and laboratory studies, accompanied by 'competent, prudent and legitimate governance',[33] see also U. S. Government Accountability Office.[39]

This sort of boundary work is not uncommon for emerging areas of techno-science. Technology assessment of nanotechnology in 2004 by the Office of Technology Assessment at the German Bundestag for example performed a kind of boundary work on nanofuturism. In the UK, in the same year, the Royal Society and Royal Academy of Engineering's report on nanosciences and nanotechnologies performed a similar function,[40] exorcising visions of 'nanobots' and 'grey goo' which were considered to be a 'distraction' from the real issues, focusing attention through expert analysis, and a measure of public and stakeholder deliberation, on the far less exotic, and arguably less contentious, engineered nanoparticles and thereby framing and legitimising a research agenda that largely stands to this day.

There is a rational, well established logic behind this: decisions based evidentially on knowledge (broadly constituted) and good science are the best ones. Policy should be evidence-based. But in doing so the report introduced a moral division of labour between research and application of SRM, distinguishing between the governance of small scale research and the governance of large field trials and deployment, arguing the need for the former while thinking about, or even preparing the ground for the latter. The caveat here is that research does not necessarily mean 'use' (see Morrow *et al.*),[41] for a discussion of analogies of geoengineering with medical research in terms of ethical principles and precedents in fields such as medicine where there is an ethical distinction between medical research and medical practice). This is a distinction which, as I will describe later, is not necessarily one that is generally held for SRM.

Rees' successor at the Royal Society continued this narrative, arguing that, faced with an impending *grand malum*, there is almost a moral obligation to research such techniques, in terms of feasibility, efficacy, safety and effects, even if the decision to use such techniques is the privilege of others and one, we may hope, that never has to be taken.

> *"One would not take a medicine that had not been rigorously tested to make sure that it worked and was safe. But, if there was a risk of disease, one would research possible treatments and, once the effects were*

established, one would take the medicine if needed and appropriate. Similarly we need controlled testing of any technologies that might be used in the future'' (Nurse, 2011, cited in Owen, 2011).[19]

If a decision has to be taken in the future concerning whether SRM presents the lesser of two evils (*i.e.* as opposed to the impacts of climate change) the argument is that such a decision should have a firm basis in good science undertake beforehand (see Gardiner[8] for further discussion on this argument).

This is echoed by those academics who posit the need to develop *capability* to do SRM in a manner that complements emission cuts, while managing the associated environmental and political risks.[12] They argue that it would be reckless to conduct the first large scale SRM tests in an emergency and that there is an immediate need for a carefully designed, incremental, transparent and international programme of SRM research, including small scale field trials (arguing it is impossible to identify and develop techniques without field testing), linked to activities that create norms and understanding for international governance of SRM.[12] Some ask whether it is indeed unethical *not* to investigate a technology that might prevent widespread dangerous impacts associated with global warming, and not provide policy makers in the near future with detailed information about the benefits and risks of various geoengineering proposals so they can inform decisions about implementation: 'only with geoengineering research will we be able to make those judgements' (see Robock, Chapter 7). If such research were blocked, only 'unrefined, untested and excessively risky' approaches would be available, constituting a 'policy train wreck'.[42]

The Royal Society recognised that the 'acceptability of geoengineering will be determined as much (if not more) by social, legal and political issues as by scientific and technical factors' and that 'there are serious and complex governance issues which need to be resolved if geoengineering is ever to become an acceptable method for moderating climate change'.[7] It saw the solution to this lying in research, development, demonstration and robust governance.

Despite advocating that geoengineering proposals should be primarily evaluated on the basis of four criteria – effectiveness, timeliness, safety and cost – it also recognised the importance of public attitudes, social acceptability and political and legal feasibility. It advocated the exploration of geoengineering governance challenges as a priority and that appropriate governance mechanisms would be needed *before* deployment of any geoengineering technology with trans-boundary implications, other than those aimed at greenhouse gas removal. It recommended research and development to investigate whether low risk methods could be made available 'if it becomes necessary to reduce the rate of warming this century'. This should include appropriate observations, the development and use of climate models, and carefully planned and executed experiments.[7] This research should be conducted in an open, transparent and internationally coordinated manner. It recommended the development and implementation of governance frameworks to *guide both research and development in the short term, and possible deployment in the longer term,* including the initiation of stakeholder engagement and a public dialogue process.[7] Any trans-boundary experiments should be subject to some form of international governance, preferably based on existing international structures.

The framing of 'properly governed research now with no presumption of use, and no deployment without international governance' has been echoed elsewhere. The American Meteorological Society (AMS) for example adopted a policy statement calling for research in July 2009, which was endorsed by the American Geophysical Union and readopted by the AMS in 2013.[43] This recommends enhanced research on the scientific and technological potential for geoengineering the climate system, including research on intended and unintended environmental responses; co-ordinated study of historical, ethical, legal, and social dimensions of geoengineering that integrates international, interdisciplinary, and intergenerational issues and perspectives and includes lessons from past efforts to modify weather and climate; and the development and analysis of policy options to promote transparency and international cooperation in exploring geoengineering options along with restrictions on reckless efforts to manipulate the climate system (see Rayner *et al.*[35] and Robock, Chapter 7, for other examples of calls for research in this vein).

3.2 Development of Normative Principles for Governing SRM Research

In the absence of regulation and other codifications of social norms, the drawing up of voluntary codes of conduct/practice for research in areas of emerging technologies and techno-science is one favoured option (see European Union, *Code of Conduct for Responsible Nanotechnologies Research*, 2008).[27] As I have described, one of the key recommendations in the Royal Society report was the development of a research governance framework, to include codes of practice for the scientific community. Rayner *et al.*,[35] and Kruger[36] describe how, shortly after publication of the report, in November 2009, two of its authors (Steve Rayner and Tim Kruger at Oxford University) initiated the development of a set of normative principles for governing geoengineering research which would subsequently become known as the 'Oxford Principles' (see Box 2).[35,36] This, Kruger describes, was initiated in response to the UK House of Commons Science and Technology Committee call for evidence into the regulation of geoengineering.

These academics and three others with expertise in social science, risk, international law and ethics prepared *Draft Principles for the Conduct of Geoengineering Research* which were submitted to the Science and Technology Committee.[44] The Members of Parliament, according to Kruger, used the Oxford Principles as a framework for questioning those who gave oral evidence to their enquiry, and stated in their report that 'while some aspects

Box 2 Normative Principles for Governing Geoengineering Research.

Oxford Principles for Governing Geoengineering Research.[35,44]

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

Asilomar Principles for Responsible Conduct of Climate Engineering Research.[47]

The Asilomar Principles propose the need for international governance and suggest several elements important to governance:

1. Collective benefit
2. Establishing responsibility and liability
3. Open and co-operative research
4. Iterative evaluation and assessment
5. Public involvement and consent

Bipartisan Policy Centre Principles for Climate Remediation Research.[33]

1. Purpose should be to protect the public and environment from potential impacts of climate change and climate remediation technologies
2. Field deployment inappropriate at this time
3. Basis and direction of research based on independent advice from experts and government officials, informed by a robust process of public engagement
4. Transparency
5. International co-ordination
6. Ongoing assessment and adaptive management

of the suggested five key principles need further development, they provide a sound foundation for developing future regulation. We endorse the five key principles to guide geoengineering research'.[45] Responding to the report, the UK Government welcomed the outline set of principles.[46] Kruger goes on to describe how the principles were then presented at the US Asilomar Conference on Climate Intervention Technologies in March 2010 organised by the Climate Institute (which consciously drew on the famous 1975 Asilomar Conference on Recombinant DNA Technologies) where they subsequently formed the basis of the Asilomar Principles for Responsible Conduct of Climate Engineering Research (see Box 2),[47] see also Olson.[21]

The Oxford Principles, in the words of its authors, 'signal core societal values that must be respected if geoengineering research, and any possible deployment, is to be legitimate'. Intended to guide the collaborative development of geoengineering governance, from the earliest stages of research, to any eventual deployment they contain the principle of ''governance before deployment'' *i.e.* one that does not advocate eventual deployment, but indicates that any decision to deploy or not must be made in the context of a strong governance structure. Rayner *et al.*[35] frame it as a process to stimulate an open debate about what values should underpin a geogengineering governance regime, and what this could look like *i.e.* what operational features of a governance regime are desirable. With both normative and process dimensions, they are analogous to high level legal principles, not intended to direct action and being similar to the codes of conduct used by medical professions and beyond. In a similar vein, the US Bipartisan Policy Center's task force on climate remediation also developed a set of six principles for guiding research (see Box 2).

These sets of principles have some distinct commonalities. They advocate firstly that geoengineering (including SRM) should be of *collective benefit*, *regulated as a public good* and for *the protection of the public and the environment*. Explaining the principle of regulation as a public good in more detail, Rayner *et al.*[35] go on to state that since all humanity has a common interest a stable climate and the means by which this is achieved, the global climate must be managed jointly, for the benefit of all and with appropriate consideration for future generations, *i.e.* invoking the concept of (intergenerational) justice. This utilitarian view does not preclude private sector involvement in technique development or commercialisation, but they argue that SRM should be undertaken in the public interest by 'appropriate bodies at a state and/or international level' (see also Parson and Keith),[42] such that activities are not dominated by a small group (*e.g.* subset of governments or business interests): activities should be governed in a way that benefits everyone and that does not privilege certain interests (*e.g.* through the patent system) in an equitable and democratic manner. There should therefore be a presumption against exclusive control of geoengineering technologies by private individuals or corporations, with fair access to the benefits of geoengineering research. I will return to this issue presently as it proved important for governance in practice (see section 4).

Aligned to this, all three sets of principles advocate public participation in geoengineering decision making, and extend this to introduce the principle of informed consent of 'those affected by research activities', which in the case of SRM would require global agreement (see also Morrow *et al.*)[41] Inclusive deliberation is an important feature of the governance framework I and other colleagues developed for the SPICE SRM project that I will describe below. Kruger[36] draws on Stirling[20] – who in turn draws on Fiorino[48] – in terms of the rationale for this as being normative, *i.e.* it is the right thing to do, legitimising decision making and substantive, *i.e.* that it makes for better decision making through an inclusive approach (see Sykes and Macnaghten for an extended discussion).[49] The informed consent principle is drawn from (bio)medical ethics (Morrow *et al.*,)[41] and introduces an important nuance to the framing presented by Nurse in his quote above. Rayner *et al.*[35] make a salient point that the mode and extent of participation will depend on global differences in political and legal cultures, where there will be different ideas about democracy and different understandings of consent.

All three sets of principles also advocate disclosure, transparency and open publication of research results (*e.g.* through production of an open research register) and international co-ordination and co-operation. Transparency is a value that repeatedly emerges as a necessary component of any geoengineering governance framework.[50] Without transparency, Rayner *et al.* argue, an agent is effectively ''kept in the dark'', with the danger of exploitation on the one hand, or benign but disrespectful paternalism on the other. Disclosure and open publication support informed consent (see Dilling and Hauser for further discussion)[50] and promote integrity of the research process, trust and the preventing of a backlash against geoengineering researchers and their research (see Kruger).[36] Linked to principles of openness, transparency and participation, all three sets of principles also advocate, in the spirit of technology assessment, iterative and independent assessment of impacts (environmental, socio-economic) of research, including the mitigation of risks of lock in (see section 3.4).

There is some distinction between the three sets of principles: the Bipartisan Policy Center's principles advocate no deployment at this time; in contrast the Oxford Principles advocate governance before deployment; meanwhile The Asilomar principles seem to skirt this issue, although in the preamble they do assert the need for international governance. The Asilomar principles instead advocate the principle of establishing responsibility and liability. This latter principle, as I and others have discussed above and extensively elsewhere, is a particularly challenging goal.[51,52]

There are some obvious ambiguities and tensions inherent within the principles (for example what constitutes 'benefit to all' and what constitutes 'independence' of assessment) that the authors recognise. The principles also combine elements of the emerging field of responsible innovation (see section 4) which broadly has both normative aspects and process dimensions under conditions of uncertainty and contingency, and which itself builds on concepts of anticipatory governance,[24,53] technology assessment,[54–56] and so called 'upstream engagement' (Sykes and Macnaghten, and references within).[49] As such SRM and geoengineering is emerging as an important location for exploring in a more general way the governance of emerging technologies.

3.3 The Solar Radiation Management Governance Initiative (SRMGI)

Following publication of its report, in March 2010 the Royal Society entered into a partnership with the Environmental Defense Fund (EDF) and TWAS, the UNESCO academy of sciences for the developing world, to investigate governance issues raised by research into SRM. The partnership initially intended to produce some specific governance recommendations for SRM research, but then changed emphasis, instead aiming to provide a forum to open up and document governance discussions that drew in different perspectives, rather than producing prescriptive recommendations. It therefore intentionally did not act as a normative guide or code for governance of SRM research but represented a set of perspectives on governance (from no special governance to complete prohibition) as a platform for further discussion and debate. Its working groups focussed on the mechanics of SRM governance, international dimensions, thresholds and categories of research and goals and concerns. It did not attempt to distinguish what types of research would require what forms of governance. It instead focussed on the functions of SRM governance, what existing international treaties and institutions might be of relevance, ways of co-ordinating and delivering SRM governance, and how a phased adaptive approach to SRM research governance might proceed.

A key question for the SRMGI was whether research explicitly focussing on SRM has any characteristics that warrant particular (and possibly novel) forms of oversight *i.e.* in addition to the norms and rules of funding, research and publication of results (including policies of open access) and ethical review procedures at research institutions . As 'strategic research' the report argued that wider publics have legitimate interest in what kinds of research are being undertaken on their behalf and whether that exploration poses a risk to them, warranting public oversight and being open to global scrutiny (this is one of the normative principles described in the Oxford Principles). Since this is a novel proposition to research technologies that, if deployed, would intentionally change the living conditions of many people across many borders, SRM research, the report concluded, may warrant global (and possibly different) forms of governance: in this regard SRM research was considered a candidate for special consideration.

3.4 Thresholds and 'Differentiated Governance'

In general, international laws and conventions provide a largely permissive framework for geoengineering research activities.[7] A cautious approach which permits carefully controlled scientific research in the field of ocean fertilisation had already been adopted under the *London Convention and London Protocol*, see Box 4.3, Royal Society.[7] The SRMGI report concluded, however, that there are few international governance mechanisms available to ensure that SRM research would be transparent, safe and internationally acceptable. It also argued that a moratorium on research would be difficult, if not impossible, to enforce.[10]

Drawing a distinction between different types of SRM research, from computer modelling to global testing, the SRMGI report argued that effective governance should be based on differentiated governance arrangements for different kinds of SRM activity.[10] This was an approach that the report noted had been adopted through the 2010 decision by the *UN Convention on Biological Diversity*, signed by 193 countries, which states that 'no climate-related geoengineering activities that may affect biodiversity take place... with the exception of small scale scientific research studies that would be conducted in a controlled setting'.[57] What was small and large scale was not defined, but the principle of thresholds and differentiated governance was set. The SRMGI report went further, defining more precise categories of research for differentiated governance:

1. *'Indoors and passive observations'*: non hazardous studies with no potential environmental impacts such as modelling studies, passive observations of nature and laboratory studies (not involving hazardous materials, or involving hazardous material but appropriately contained and with no deliberate, intentional release into the environment): these were considered to be activities with negligible direct risks.
2. *'Outdoors activities'*:
   (a) small field trials (including release into the environment) of a magnitude, spatial scale and temporal duration that may lead to locally measureable environmental effects considered to be insignificant at larger scales – these were considered to be activities with negligible direct risks;
   (b) medium and large scale field trials (including release into the environment) leading to measureable and significant environmental effects, categorising medium field trials as having effects at local or regional levels, but not beyond national borders and categorising large field trials as those having global or large scale effects across borders: these were considered to be activities with potentially direct risks; and
   (c) deployment, leading to environmental effects of a sufficient magnitude and spatial scale to affect global and regional climate significantly and lasting for more than one year: these were activities with potentially direct risks.

What is immediately apparent from this is the reliance on risk as a differentiator. The report itself recognised that physical risk is not the only consideration, with 'public perception' being an important dimension, itself influenced by factors such as who is undertaking the research and for what purpose, reversibility and liability arrangements. The report did not attempt to go to the next step of identifying what governance arrangements should be assigned to each of the categories above, although the categorisation above rather implicitly draws a line between on one hand indoor activities and small scale field trials involving release into the environment with only local environmental effects, and on the other medium and large field trials/deployment, in terms of the potential for direct risks (see also Boucher *et al.*,[15] who suggest that localised climate modification should be classified as an adaptation measure as long as there is no measurable remote environmental effects). The report was careful in its use of language:

''It seems clear that large-scale SRM interventions would pose potential risks and provoke contending views that would require effective governance, whether these interventions are undertaken as operational deployments or as large-scale research. It is less clear, and less widely agreed, that smaller-scale SRM research activities pose similar challenges that would require new governance mechanisms'' (SRMGI, p. 29).[10]

The strategy of differentiated governance based on thresholds has also been recommended by a number of academics in the field (*e.g.* Cicerone[58] and Robock, Chapter 7). Robock distinguishes between research and deployment in terms of environmental impact, asserting that indoor research has different ethical issues to that conducted outside. In his view, curiosity-driven indoor research cannot and should not be regulated if it is not dangerous, but any emissions to the atmosphere should be prohibited if they are dangerous. Here indoor research is framed as ethical and necessary to provide information to policy makers in order to make informed decisions in the future, and outdoor research is unethical unless subject to governance that protects society from potential environmental damage. Parson and Keith[42] have also recommended a strategy based on 'defining thresholds, accepting oversight'. Asserting that low-risk, scientifically valuable research should be allowed to proceed and that large regulatory burdens could create incentives to mislabel the research's purpose, they identify three next steps to 'break the deadlock on governance of geoengineering research': (a) that government authority should be accepted – asserting that an approach of Polanyi-esque self regulation is unacceptable,[59] they advocate informal co-ordination by research funders and regulatory agencies, but with no new laws; (b) that a moratorium should be declared on large scale geoengineering with a possible 'large scale threshold' such that there is no detectable climate signal; and (c) that a 'small scale threshold' be defined below which research may proceed, based on existing regulations, possibly with modest new requirements and transparency.[42] Parson and Keith suggest thresholds based on a product of the area, duration and size of radiative forcing perturbation.

4 From Saying to Doing: Governing SRM Research within a Framework for Responsible Innovation

In response to one of the Royal Society's key recommendations (for government and research councils to fund a ten year programme of research), in October 2009 the UK research councils convened a workshop to scope a programme of geoengineering research aimed at allowing the UK to make an informed and intelligent assessment about the development of climate geoengineering technologies. Following this, in mid March 2010 several of the UK Research Councils, under the leadership of the Engineering and Physical Sciences Research Council (EPSRC), convened a funding 'sandpit' on the topic of geoengineering. Sandpits are an innovative funding approach in which participants (*e.g.* scientists) are encouraged to work across institutions and disciplines to develop novel project ideas over an intensive couple of days with help from mentors, and using an iterative process of real time peer review, with the intention of funding one or more projects by the end of the process. The geoengineering sandpit resulted in two projects being funded. One was a desk-based project aimed at developing an integrated assessment framework and tools for assessing geoengineering proposals, the other was a project called SPICE: Stratospheric Particle Injection for Climate Engineering. The aims of SPICE were, broadly, to investigate: (a) what types of particles could be injected into the stratosphere for the purposes of SRM and in what quantity; (b) how these particles could be deployed stratospherically; and (c) what impacts might be associated with deployment. The second objective included a proposed field trial in which a hose would be tethered to a balloon at 1 km altitude, through which small quantities of water would be pumped; the aim was to understand the dynamics and behaviour of the tethered balloon configuration in order to inform the design of a 20 km high deployment system (see Figure 1).

It was an engineering 'testbed' with no likely direct impacts and which easily fell under 'a small scale threshold below which research may proceed, based on existing regulations, possibly with modest new requirements and transparency'.[42] The testbed passed through the ethical approval processes at the universities concerned with little or no comment.

Given the known wider dimensions (and sensitivities) of SRM outlined in the Royal Society report and elsewhere it was proposed during the sandpit that the funds for the proposed field trial be made available subject to an independent 'stage gate' review. Stage gating is an established mechanism used in innovation management (particularly in new product development) in which investments in the innovation process are phased (or staged), with decision 'gates' where decisions are made to progress, stop, refine, redefine *etc.*, usually on the basis of technical feasibility, market potential and risk.[60] Having decided that this governance approach would be used, it then became necessary to define firstly what criteria would be used at the decision gate to support a decision to allow the field trial to go ahead (or not) and secondly who would make the decision. A meeting was convened in the late Autumn of 2010 to consider this. Representatives of the research councils, SPICE team (scientists and engineers) and social scientists (including at least one of the authors of the Royal Society report and Oxford Principles) struggled to develop a consensus on this, indeed I recall a lively discussion. At the end of the meeting I spoke with the EPSRC representatives about drawing together some criteria based on the discussions and further insights from the concept of responsible innovation I and others had been thinking about, notably as this applies to the activities of research funders.[61] Box 3 summarises these criteria, with more details provided by Stilgoe *et al.*, (2013).[62]

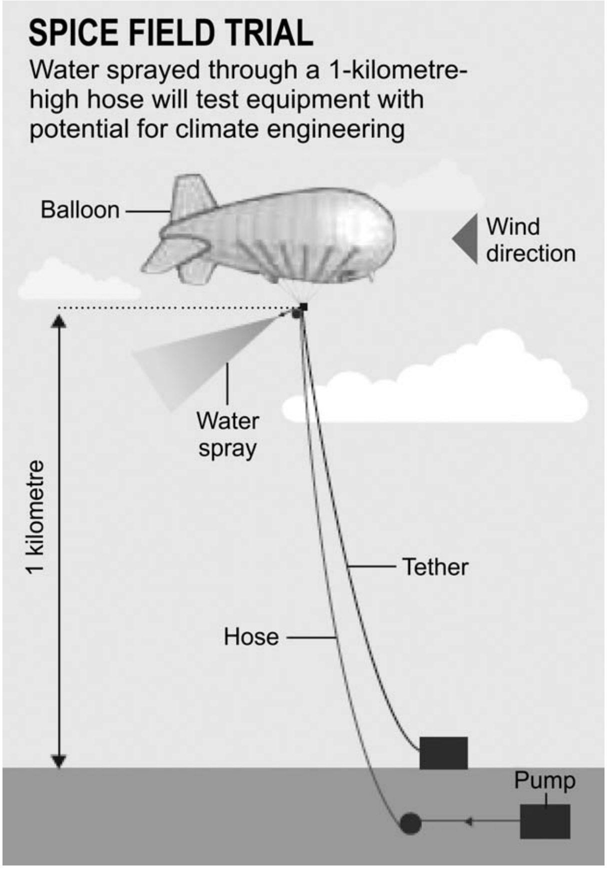

Figure 1 SPICE Testbed.
(From Macnaghten and Owen, 2011).[65]

They involved consideration of direct risks, safety and regulatory compliance (*e.g.* for flying tethered balloons) associated with the testbed itself (criteria 1 and 2), for which the SPICE team were asked to submit a risk register and statement of regulatory compliance. The third criterion required the SPICE team to reflect on the project's framing and communication, asking them to develop a communication plan to allow dissemination about the nature and purpose of the testbed (this also refers to the normative principle of transparency in Box 2). This plan was to be informed by dialogue with stakeholders. Criterion 4 asked the SPICE team to anticipate, reflect on and describe the envisaged applications of their research and the impacts (intended or otherwise) these applications may have, and embed mechanisms to review these as more information became available in the future (given the inevitable uncertainty associated with the research). It asked them to broaden their visions of application and impact, to think through other pathways to other impacts, to contextualise their work within a review of the

Box 3 SPICE SRM project stage gate criteria and responsible innovation framework dimensions.
(Reproduced with kind permission of Elsevier).[62]

	Criteria	*R I Dimensions*
1.	The testbed deployment is safe, the principal risks have been identified and managed, and are deemed acceptable	Reflexivity
2.	The testbed deployment is compliant with relevant regulations	Reflexivity
3.	The framing of the project (nature, purpose) for external communication is clear and advice regarding this has been obtained	Reflexivity, Inclusive deliberation
4.	Future potential application(s) and associated impact(s) have been described and mechanisms put in place to review these as significant information emerges	Anticipation, Reflexivity
5.	Mechanisms have been identified to understand wider public and stakeholder views regarding these envisaged applications and impacts	Inclusive deliberation, Reflexivity

known or potential risks and uncertainties of SRM and the questions (social, political, ethical) that might arise as the testbed is projected through to deployment. This again refers to the principles of iterative evaluation and assessment described in Box 2. The final criterion asked the SPICE team to identify mechanisms to understand public and stakeholder views around the project and its envisaged applications and potential impacts, and the understandings, assumptions, uncertainties, framings and commitments associated with these. This builds on the principles of public participation and engagement in Box 2. This was in part informed by a series of micro-deliberative public forums,[63] which I will describe in more detail in the next section. These criteria were aligned to a framework for responsible innovation I had been developing with others and which is in turn based on the need for research and innovation to be *anticipatory, reflexive, inclusively deliberative* and (ultimately) *responsive* (to such anticipation, reflexivity and deliberation) in terms of its direction and trajectory, in such a way that innovation and its underlying purposes, motivations and impacts are opened up,[51,62,64] empowering a measure of social agency in technological choice.[20] These dimensions are mapped on to the criteria in Box 3.

Having defined the criteria around a framework for responsible innovation and agreed how the SPICE team, working with others, might respond, it was then necessary to define how these responses would be evaluated and by whom. The stage gate panel that was convened to undertake this task did so in June 2011 and comprised two social scientists, an atmospheric scientist, an engineer with expertise in high altitude balloons, and an advisor to an environmental NGO,' observed by members of the research councils and myself. observed by members of the research councils and myself. The panel was charged with providing a recommendation for each of the five criteria (pass, pass pending further information, fail) to the research councils who would make the final decision concerning the future of the testbed.[65]

The panel decided, after considerable discussion, rebuttal and debate, that the first two criteria, concerning safety, risks and regulatory compliance associated *with the testbed itself*, were convincingly passed: there appeared to be little concern about the direct risks, environmental or otherwise, of releasing a bath tub full of water over an airfield in an unpopulated location. This, as I will very shortly describe, was not to be the issue with SPICE.

The other three criteria would only be passed pending further work and provision of further information. There were particular concerns regarding the need for a communications strategy informed by stakeholder engagement and underpinned by substantive public dialogue, more anticipation and reflection concerning the testbed and projection through to deployment (in terms of different, plausible pathways through to application and the impacts and implications the tested and envisaged applications may have – social, ethical, environmental, intended and unintended), and, finally, substantive engagement with stakeholders concerning the project and its intended application(s). The governance process asked the SPICE scientists and research funders to consider the wider (*e.g.* social) dimensions of a technoscience 'in the making', one in which established role responsibilities (of both scientists and funders) were challenged and broadened,[66,67] and one in which the very premise of the independent republic of science and its role responsibilities were questioned.[59] This was a draining but important experience for many concerned. It was also clear that it would require resourcing and support, (for example the commissioning of the public engagement work described by Pidgeon *et al.*). Ultimately it raised questions about the way the project had been set up largely as one investigating technical feasibility and environmental impacts, but not the social, ethical and political dimensions I have described in previous sections of this chapter. Amongst these was the question of whether the project should have been funded at all. It is very important to note in this regard that it was made clear by the research councils at the beginning of the stage gate meeting that the ethical question of whether the SPICE project should have been funded was not for discussion: whether SPICE should have been made an object of governance (using the framework we had devised or otherwise) was not for debate. This, many (including myself) feel was a distinct limitation and I remain of the firm belief that the process would have been a far better, and more legitimate one, had the dimensions of responsible innovation been in place for use by the research councils at the original 2009 workshop and 2010 sandpit in which decisions to fund geoengineering research, and if so of what type and in what way, were made.

On September 26th 2011, following a meeting with myself, the Stage Gate Panel Chair (Phil Macnaghten) and members of the SPICE team, the research councils decided to postpone the testbed until the pending actions had been addressed, with the intention of convening the stage gate panel again to review this later that year (see Appendix 1). On that very same day the research councils received a letter, copied to the then UK Secretary of State for Energy and Climate Change and signed by more than 50 NGOs, demanding that the project be cancelled. The NGOs saw the testbed as symbolic, sending the wrong signal to the international community, deflecting political and scientific attention from the need to curb greenhouse gas emissions.[68] There was grave concern that its 'sole purpose is to engineer the hardware that would later allow chemicals to be injected into the stratosphere to reflect sunlight' as 'a dangerous distraction from the real need: immediate and deep emissions cuts'. This would 'condemn future generations to continue a high-risk, planetary-scale technological intervention that is also likely to increase the risk of climate-related international conflict'.

With mounting interest in the media and beyond, the SPICE team began to address the outstanding stage gate criteria. It was as part of the subsequent discussions that the projects principal investigator became aware of the existence of a patent application for the balloon-tethered hose delivery system,[69] submitted by one of the sandpit mentors just prior to the sandpit itself and including two of the SPICE project scientists as named inventors. Although an internal review conducted later by EPSRC found no evidence that research council policies on vested/conflict of interest had been broken, it was clear that the patent posed a significant issue for the project in terms of the nature of at least some of the participants motivations, as well demonstrating a lack of disclosure, which was hardly in the spirit of the Oxford Principles. In May 2012, after discussions between the research councils, the SPICE team and myself, the principal investigator of the SPICE team decided to cancel the testbed (see Appendix 1), instigating a more formal process of stakeholder engagement (see section 5) which at the time of writing is ongoing.

5 A Social Licence to Operate?

> *"Any response to a global problem might be rejected as illegitimate and unacceptable if the majority of the world's population played little role in . . . approving the response" (SRMGI, p. 25).*[10]

There has been only limited stakeholder and public engagement concerning SRM. It should be noted that both the Royal Society and SRMGI reports both included consultation with stakeholders and the public. Since then there have been a few academic studies which provide some interesting insights concerning perceptions and framings of SRM and its governance. Stilgoe *et al.* describe some preliminary results of stakeholder engagement around the SPICE project,[23] which highlights the fact that questions of purpose and motivation were of paramount importance. Aligned to this, governance thresholds for research and deployment proposed by the SRMGI[10] and Parsons and Keith[42] were deeply contested. A primary reason for this is what the authors describe as ‘the imaginary made real’. While stakeholders recognised that the SPICE testbed would not itself pose any direct risks it was perceived as a *symbolic act,* a potential signifier of intent. There were concerns that research may generate its own momentum and create a constituency in favour of deployment and/or that the UK might be preparing to proceed down a different strategy to carbon mitigation and adaptation using a very high risk technological approach, representing a slippery slope.[3,8]

This was not about risks but about purpose and motivation: the patenting issue that surfaced as part of questioning following the stage gate process brought these concerns into sharp relief. It called into question the legitimacy of a differentiated governance strategy based on thresholds as described in section 3. Fundamentally, SRM technology was perceived as being inherently entangled with politics (see section 2), *irrespective of the type of research done*. SRM was perceived not just as a technology, but as a political artefact.

Familiarity with SRM amongst the public is as yet low,[2] with seemingly little increase in awareness over the last five years. Pidgeon *et al.*[63] describe the results of a series of focus groups undertaken in response to recommendations from the SPICE stage gate panel that used an invited micro-deliberation methodology to understand framings of SRM and the SPICE project. This revealed that almost all participants were willing in principle to allow the testbed to proceed, but that very few were comfortable with the idea of deployment. Questions that arose included those of testbed safety and direct risks, as well as more general questions that demonstrated *projection* by participants of the research through development to deployment, with questions concerning the knowledge that the testbed might provide and its utility.

The participants felt that SRM could only provide a stop gap response to climate change, *i.e.* ‘buying time’, with concerns about the perceived naturalness of SRM interventions *i.e.* that SRM was perceived as interfering with natural processes (this was investigated in more detail by Corner *et al.*, 2013 who found that ‘messing with nature’ was a dominant narrative common to the public engagement exercises they undertook, but that this constituted a subtle set of discourses).[2] Pidgeon *et al*. report that SRM was also perceived as contributing to a ‘disassociation of human kind with the physical world’,[63] where SRM may be thought of as being a product of a misguided world view.[9] There were also questions about governance and specifically how SRM would be regulated and communicated. An international system aimed at enabling *a global debate concerning SRM* was seen as important. I will return to this point in the final section of this chapter.

Overall, the perceptions, associations, and interpretations of SRM deployment were negative. However, this did not automatically inhibit support for the testbed when this was framed as a *strictly limited research activity*. Participants were reluctant to rule out the SPICE field trial on condition this would be undertaken as a limited science and engineering test, but at the same time they exhibited discomfort concerning what might happen if the trial went ahead. Ambivalence towards the testbed *simultaneously* translated into concerns and opposition about deployment.

5.1 Conditionality and Implausibility

Conditionality was a key observation made by Macnaghten and Szersynski who also used a deliberative focus group methodology to engage publics with SRM.[4] These authors focused explicitly on the lived future and perceptions publics had concerning the kind of world that SRM could possibly bring into being. Thematic analysis of the engagements highlighted that SRM might be publically acceptable only under very specific and highly contingent conditions (see Box 4), conditions that by and large were seen as highly implausible in terms of their potential to be met (see also Jamieson),[3] and with perceptions that SRM was an unnatural intervention (see Corner *et al.*, on this

Box 4 Perceived conditions and plausibilities for SRM. (Adapted from Ref. 4)

1. *Scientific robustness*. There is confidence in the science of climate change as a reliable basis for policy. Only if people believe in the ability and authority of climate science to predict with confidence can policies aimed at climate remediation gain traction. Low plausibility: this confidence was rarely held by participants.
2. *Accurate research foreseeability.* Confidence in the ability of research to anticipate reliably the side effects of SRM in advance of deployment. Low plausibility: there was little belief in the capacity of science to identify side effects reliably in advance. Perceptions of messing with nature were seen as inevitably leading to nasty surprises. We would be 'living the global experiment' which will become part of the human condition.
3. *Condition of the ability of research to demonstrate efficacy*. Participants registered considerable doubt about technical feasibility of SRM. Only on deployment could efficacy really be ascertained.
4. *Condition of good intent and effective governance*. Confidence of the motivation of SRM as being complementary to adaptation and mitigation; confidence that SRM will be used exclusively by governments with the motivation to counteract anthropogenic climate change. Low plausibility: good intentions could never be guaranteed, being potentially open to 'dual use', used to further national, regional or commercial interests at odds with the purpose of counteracting climate change.
5. *Condition of democracy*. Confidence in the capacity of existing political systems to accommodate SRM. Low plausibility: global governance intensely difficult to achieve within democratic political arrangements, with current omens (*e.g.* lack of consensus on mitigating climate change) being poor and with SRM only being governable under autocratic governance arrangements.

point),[2] one that would constitute a short term fix that increases the likelihood of geopolitical conflict and presents major threats to democratic governance.

The discussions were nuanced and not polarised, but even those participants who started from a position of conditional acceptance grew to perceive the conditions for successful and acceptable deployment as being unfeasible and implausible, *i.e.* the more people learned about SRM technology the more sceptical they became. Since effects were perceived by some to be knowable only on deployment there was scepticism of even limited research into SRM. The authors questioned whether principles of regulation of geoengineering as a public good and public participation outlined in the Oxford Principles were attainable, arguing that upon deployment SRM could only be controlled centrally and on a planetary scale, with little opportunity for opt out.

6 Conclusions: Governing a New End of History?

In this chapter I have described some emerging proposals to engineer the Earth's climate through solar radiation management, and discussed aspects of governance as this relates to both research and deployment. It is clear from this discussion that SRM presents significant governance issues. SRM is a political artefact, a type of post-normal technoscience,[70] which makes it is a far from straightforward object of governance.[4] It is also apparent that there is distinct political unease with the notion of deployment. Where the views of publics and stakeholders have been sought, these have also highlighted great concern with, and often opposition to, the possible deployment of SRM. Many scientists frame their research as objectively informing a decision that they hope will never have to be taken. Almost everyone seems to agree that if this unpalatable decision has to be made, then there must first be international agreement and robust mechanisms of international governance in place. It is also clear that the tiered governance strategy suggested by learned societies, some governments and some academics, which distinguishes between desk-based and laboratory research, and small scale field trials on one hand, and large scale field trials and deployment on the other, is a contested one. In this regard, differentiated governance that is based mostly on the potential for direct risks is wholly insufficient: while risk and uncertainty are undoubtedly important to many, issues of purpose, motivation and intent of research, development and use are key. Historically, technological governance has struggled with intent. Creating governance thresholds for research and deployment has neglected a fundamental issue: that research and projection through to application operate as simultaneous and (socially, politically, ethically) entangled frames. Here research, even of any kind, may be symbolic, a signifier of intent, the beginning of a slippery road, with concerns of moral hazard and lock-in. For some stakeholders this imaginary made real generates concerns and even hostility towards SRM research. The little public engagement that has been undertaken suggests a lack of awareness of SRM, and ambivalence towards SRM research, which leads to significant concerns when people understand more about the proposed technology and project through from the research to application. The projection, entanglement and simultaneous framing is crucial to how we think about SRM and its governance: questions about the research *cannot be disaggregated* from questions about what the research could lead to and why the research is being undertaken, precisely because, unlike other techno-scientific umbrella terms such as 'synthetic biology' or 'nanotechnology' where purpose and application may not be immediately clear, SRM is defined by its purpose, and the plurality of goals, motivations and framings that lie beneath. Research, development and application become deeply entangled and cannot be arbitrarily or artificially separated. By doing so a strategy of differentiated governance is in danger of ignoring the core, ethical questions so central to SRM.

Conditionality (*e.g.* upon there being robust mechanisms of research governance, upon there being international agreement and governance before deployment) is a key feature of governance discourses relating to SRM and its research. Rather ominously, early findings seem to indicate that there is a sense of deep implausibility that such conditions could ever be met, particularly on an international scale. Concerns about the development and use of SRM in the absence of such conditions being met are profound, and include the potential for geopolitical conflict, challenges for democracy and democratic governance, and the potential to generate autocratic forms of governance. There is a common sense that we will be living a global, social and political experiment that will redefine our relationship with nature, uncertainty and the human condition: an experiment that many have concerns will be either workable, or desirable.

And so I return finally to the questions I posed at the beginning of this chapter. Firstly is SRM a legitimate object of governance? I believe that despite the boundary work I have described which has attempted to legitimise SRM research this is a question that remains outstanding. The success of a technological fix will depend on how it is framed,[18] and who defines the criteria for success:[9] these criteria, or conditions, must be democratically and equitably defined.[3,19] It might be argued that the boundary work undertaken to date could risk creating 'high entry barriers against legitimate positions that cannot express themselves in terms of the dominant discourse' where 'normative assumptions have not been subjected to general debate'.[18] Since SRM is primarily a political artefact where, as I have suggested, research and deployment may be perceived in simultaneous frames, as awareness becomes greater I suggest this issue of legitimacy will become increasingly contested: in fact the history of emerging technologies seems to predict this, and few have been on this hubristic scale. Addressing this question in a democratic, inclusive and substantive way is, I believe, an imperative. Morrow *et al.*,[41] drawing on principles in medical research ethics, describe this in terms of a principle of respect. Here norms for conducting SRM research are located in a *prior* discussion about whether research should be conducted at all, and if so under what conditions. It involves the securing of the global public's consent, which Morrow *et al.* assert should be voiced through government representatives before empirical research begins.[41] But assuring such 'consent by proxy' begs their key question to be answered: what representative bodies if any have authority, and legitimacy, to consent to SRM research on behalf of global publics?[3]

Secondly, and linked to the first question, is SRM practically, feasibly governable? It seems to me that we can develop open and transparent forms of SRM research governance that ensure such research is anticipatory and reflexive to its possible impacts, goals, motivations, commitments and that it is inclusively deliberative, inviting perspectives, seeking questions and ensuring that SRM research and innovation are responsive in turn. We can strive to prevent path dependency and lock in.[22] We can strive to procure 'socially robust knowledge',[71] to ensure research does not lead unreflexively to development.[3] We might even underpin these with normative principles and codes of practice. We should certainly seek to open up SRM research and ensure there is social agency in the choices and directions it takes,[20] to make it more publically accountable.[18] However, it is clear that this will require international agreement, strong institutions, and (fundamentally) a distinct culture change when this comes to science, innovation and its governance more generally: this cannot be guaranteed.

It is also clear that many find anything other than extremely limited, contained types of research deeply concerning, that even research of this limited kind is also problematic for some (possibly more than some) and that the idea of deployment is unacceptable to most without conditions that may well be implausible, and even impossible to meet. Of these conditions many remain deeply sceptical that SRM deployment can be internationally agreed upon or internationally governed, and that deployment, and indeed even research, could pose significant issues for democracy and generate conflict. It is hard to conclude anything other than the fact that SRM may well be ungovernable without very significant changes to how we govern society itself. Such grand political and social experiments have been attempted before in our history, with mixed results. In this regard proposals to research and deploy SRM are, in effect, proposals for a new end of history: one that few want and one many are sceptical can be governed. I am inclined to think that this is a social and political experiment that we should embark upon not with hubris, but with a profound sense of humility.

Postscript

As I finished writing this chapter the International Panel on Climate Change published its *5th Assessment Report*.[72] Within this the IPCC makes explicit reference to the potential for SRM geoengineering, if realisable, to substantially offset a global temperature rise, but notes that limited evidence precludes a comprehensive assessment of SRM and its impact on the climate system. It goes on to state that SRM methods will carry side effects and long-term consequences on a global scale.

Appendix 1 Transcripts of Engineering and Physical Sciences Research Council (EPSRC) Announcements regarding postponement and cancellation of the SPICE testbed.

Update on the SPICE Project (September 29th 2011) http://www.epsrc.ac.uk/newsevents/news/2011/Pages/spiceupdate.aspx (last accessed 7/2/14)

Stratospheric Particle Injection for Climate Engineering (SPICE) is an EPSRC, NERC and STFC-funded project that includes a work package on assessing the feasibility of injecting particles into the stratosphere from a tethered balloon for the purposes of solar radiation management.

EPSRC has taken the decision to delay the experiment planned in October, to allow time for more engagement with stakeholders. We have adopted a responsible innovation approach with this project – as part of our commitment to responsible development – and our decision to pause the testbed experiment reflects the advice that we have received from our advisory panel following a stage gate.

The technology test would have involved pumping water to a height of 1 km through a suspended hose, held aloft by a helium-filled balloon. This would allow the engineers to study how the hose and balloon behave over time in a variety of weather conditions.

SPICE Project Update (May 22nd 2012) http://www.epsrc.ac.uk/newsevents/news/2012/Pages/spiceprojectupdate.aspx (last accessed 7/2/14)

Stratospheric Particle Injection for Climate Engineering (SPICE) is an EPSRC, NERC and STFC-funded project that is investigating the feasibility of injecting particles into the stratosphere for the purposes of solar radiation management, *i.e.* reflecting a small percentage of the sun's light and, or heat back into space.

This involves considering different types and quantities of particles and where they could, hypothetically, be injected into the atmosphere to effectively and safely manage the climate system. It is also looking into how particles might be delivered and the likely impacts on the climate and environment.

The SPICE project includes a work package to examine the viability of using a tethered balloon and hose mechanism as a delivery method to inject particles. The work package that contains this testbed element accounts for approximately £500 000 of a £1.6 million project grant.

The SPICE project team and the research councils have chosen to follow a responsible innovation approach to the project. Responsible innovation encourages approaches that can be used early on in the innovation process to promote the responsible emergence of novel technologies in society and the identification of their wider impacts and associated risks.

The responsible innovation approach for this project included a stage gate. This is where a panel of external experts considered the progress of the project against a number of criteria, such as checking that mechanisms have been identified to understand wider public and stakeholder views on the envisaged applications and impacts.

Following the stage gate meeting, the panel advised the research councils and the SPICE team that further work on stakeholder engagement and the social and ethical implications was required. In addition, EPSRC, acting on advice from the panel, decided to delay the planned testbed experiment which would have used a tethered balloon and hose to disperse water at a height of 1 km, until this further stakeholder engagement had been undertaken.

EPSRC has provided additional funding for expert researchers to carry out this work on stakeholder engagement which includes discussion of issues around the commercialisation of geoengineering research; this is in progress and will continue.

As a result of the stage gate and the responsible innovation approach, the SPICE team was also encouraged to explore issues connected to the potential future use of geoengineering technologies. Intellectual property and need for governance in the field of geoengineering became, and continue to be, matters that concern them.

Given these issues and the existence of a patent application for an invention to deliver particles *via* a tethered balloon system, the SPICE team has decided not to conduct the 1 km testbed experiment. We received formal confirmation of this from the team on May 22, 2012. This decision is accepted by EPSRC, NERC and STFC.

The SPICE team is committed to putting all the results arising from the SPICE project into the public domain, without delay and according to normal academic practice. The SPICE team and EPSRC have agreed that this should be a condition of the grant. The results arising from SPICE will not be patent-protected.

EPSRC and the SPICE team support the Oxford Principles on Regulation of Geoengineering, which were endorsed by the House of Commons Science and Technology Committee's report on *The Regulation of Geoengineering* (March 2010).

Acknowledgments

The catalyst for this chapter stems from my involvement in a recent paper with Bron Szerszynski, Phil Macnaghten, Matt Kearnes and Jack Stilgoe in which we began to think about the political dimensions of SRM and its potential implications for democratic governance.[28]

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