The Oxford Principles.

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Climate Geoengineering Governance (http://geoengineeringgovernanceresearch.org) is a research project which aims to provide a timely basis for the governance of geoengineering through robust research on the ethical, legal, social and political implications of a range of geoengineering approaches. It is funded by the Economic and Social Research Council (ESRC) and the Arts and Humanities Research Council (AHRC) - grant ES/J007730/1

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The Oxford Principles

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Introduction

Climate change geoengineering, defined by the United Kingdom's Royal Society as "the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change (Shepherd et al 2009:1) is receiving growing attention in the climate policy discourse. As well as the Royal Society, calls for increased research into geoengineering have come from: the Institute of Mechanical Engineers (2009) and the House of Commons (2010) in the UK, in the USA: Novim (Blackstock et al. 2009), the Government Accountability Office (2010), the Congressional Research Services (Bracmort et al., 2011), and the Bi-Partisan Policy Center (Long et al., 2011) and, in Germany, the Ministry for Education and Research (Rickels et al., 2011). The Intergovernmental Panel on Climate Change (IPCC) has published a report on geoengineering technologies (IPCC 2012) and will review geoengineering in its forthcoming Fifth Assessment Report.

Research in many disciplines, from climate science to engineering, to law, economics, politics and ethics, will be necessary to understand and deal with the challenges of developing geoengineering technologies. The Royal Society report concluded that "The acceptability of geoengineering will be determined as much by social, legal and political issues as by scientific and technical factors. There are serious and complex governance issues which need to be resolved". The report went on to recommend "The development and implementation of governance frameworks to guide both the research and development ... and possible deployment" (Shepherd et al., 2009, p57).

Following publication of the Royal Society report, the UK House of Commons Select Committee on Science and Technology initiated an inquiry on the topic of how geoengineering should be governed. An ad-hoc group of academics, including two members of the Royal Society Working Group, submitted a list of five high-level principles (Rayner et al. 2009) for governance of research, development and any eventual deployment of geoengineering technologies. They subsequently became known as The 'Oxford Principles' (The Economist 2010, p75).

The Oxford Principles are not the first set of principles proposed in relation to geoengineering. Long before climate geoengineering began to be taken seriously, Dale Jamieson proposed four principles covering the deployment of technologies that could cause "intentional climate change" (1996). Another set of principles for geoengineering research, modelled on the Belmont Principles for human subject research have been proposed (Morrow et al. 2009). However, the Oxford Principles have been the most influential, inside and outside of academia. In the international scientific community, the Oxford Principles were presented to the Asilomar Conference on Climate Intervention Technologies and "generally endorsed" by the conference (The Economist 2010, p75). The conference report presented five recommendations for the conduct of geoengineering research, "drawing particularly from the issues identified in the Oxford Principles" (Asilomar

Scientific Organizing Committee (ASOC) 2010, p8)). In UK policy, the final report of the Science and Technology Committee stated that "While some aspects 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*" (Great Britain, Parliament, House of Commons Select Committee on Science and Technology 2010, p35). In turn, the Government subsequently endorsed the Committee report, including the Oxford Principles (Great Britain, Department of Energy and Climate Change 2010).

Notwithstanding this modest success, as might be expected of any regulatory innovation in a new area of scientific research, there has been some confusion about the function and content of the Principles and also about how they are to be implemented. The purpose of this article is therefore three-fold: 1) to explain the motivations for and intended functions of the Oxford Principles, 2) to elaborate on the societal values they were intended to capture, and 3) to propose a possible structure for the development of specific guidelines or protocols for different kinds of technology to ensure that the Principles are adhered to in an appropriate manner. We begin by explaining the concept of geoengineering, the reasons why interest in it is increasing, and the concerns it raises.

How Might We Geoengineer The Climate?

In the climate change context, the term "geoengineering" refers to a broad range of potential technologies which might eventually be used to alter the global climate system.[1] In considering geoengineering, it is essential to emphasize that mature geoengineering technologies do not yet exist, although some of the components that might go into them are already available or are under development for other reasons. It is equally vital to

[1] Some prefer to use the term "climate engineering", "climate geoengineering" or "climate intervention" to make clear the link with the global climate.

recognize that the term geoengineering currently encompasses a wide variety of concepts exhibiting diverse technical characteristics – and accordingly, with very different implications for their governance. Twenty-three different potential technologies were listed in the Royal Society report (Shepherd et al., 2009). The wide variety of technologies suggests the need for a preliminary taxonomy of technology concepts that identifies salient characteristics for both research and governance considerations. Geoengineering technologies are now conventionally divided into two principal mechanisms for moderating the climate by geoengineering. One is by reflecting some of the sun's energy back into space to reduce the warming effect of increasing levels of greenhouse gases in the atmosphere. This is described as Solar Radiation Management or SRM. The other approach is to find ways to remove some of the carbon dioxide from the atmosphere and sequester it in the ground or in the oceans. This is called Carbon Dioxide Removal or CDR.

Another way of discriminating between geoengineering technologies cuts across the distinction between SRM and CDR. Both goals can be achieved by one of two different means. One is to put something into the air or water or on the land's surface to stimulate or enhance the natural processes that contribute to the global climate system. For example, injecting sulphate aerosols into the upper atmosphere imitates the action of volcanoes, which we know to be quite effective at reducing the sun's energy reaching the earth's surface. Similarly, we know that lack of iron constrains plankton growth in some parts of the ocean. Adding iron to these waters could enhance plankton growth, taking up atmospheric CO_2 in the process. These technologies might be called environmental systems enhancement technologies. The other approach to both SRM and CDR is through more traditional engineering. Space mirrors, either in orbit or at the so-called Lagrange point between the earth and the sun, would be a way of reflecting sunlight (SRM), while a potential CDR technique would be to build machines to remove CO_2 from ambient air and inject it into old oil and gas wells and saline aquifers in the same way that is currently proposed for (CCS) technology. Combining these two means (environmental systems enhancement and traditional "black box" engineering) with the two goals described above (SRM and CDR) creates a serviceable typology for discussing the range of options currently being considered under the general rubric of geoengineering (Table 1).

Why Geoengineer The Climate?

The primary reason for the increasing interest in geoengineering is concern over the slow process of international negotiations to reduce emissions of greenhouse gases (GHGs). Geoengineering has been occasionally mooted since the mid-1960s, particularly in the USA (see The President's Scientific Advisory Committee 1965; Budyko 1977; Marchetti 1977; US National Academy of Sciences 1992), but was not taken very seriously in climate change discourses until an article in *Climatic Change* by the Nobel Prize-winner Paul Crutzen (2006) brought it into the mainstream. Crutzen's article broke a self-imposed and widely observed taboo in the climate science community by suggesting that research into stratospheric sulphate aerosol particle injection should be actively pursued. Leading scientists have begun to talk publicly about the potential for geoenginering to be a "Plan B" (eg. Kunzig & Broecker 2008; Walker and King 2008; O'Connor and Green 2009). There are many reasons for this. Firstly, the world is nowhere meeting mitigation targets. The world seems to be locked in to the highest emissions trajectory envisaged by the IPCC (see Figure 1). Secondly those mitigation targets might themselves be dangerously optimistic. In devising all of its emissions scenarios, the IPCC assumed that the amounts of energy and of carbon needed to create each new unit of global wealth (GDP) would continue to fall (and at a higher rate than has hitherto been observed). A couple of years ago, this trend went into reverse, largely due to rapid expansion in the emerging economies of China and India. Figure 2 shows one estimate of the total avoided emissions that would be necessary over the course of the 21st century should the IPCC assumptions turn out to be incorrect. Thirdly, some geoengineering measures appear to offer humanity the ability to shave the peaks off CO2 driven emissions and avoid tipping points. Wigley (2006) argues that sulphate particle injection might be used to “buy time” in reducing CO2 emissions. This potential to shave peaks would go some way to addressing the concern voiced by some that temperature rises over the next century may exceed irreversible “tipping elements” (Lenton et al., 2008) in the climate system leading to drastic changes with potentially catastrophic impacts on human and natural systems (Crutzen 2006; Long et al., 2011). For example, some scientists have publicly expressed concern about the melting of Arctic sea ice (see Collins, 2011). Fourthly, mitigation activities may exacerbate warming in the near term. As Crutzen pointed out, current CO2 emissions are accompanied by emissions of sulphate aerosols that reflect sunlight back into space and so partially offset the warming effects of CO2. If humanity is successful in reducing carbon emissions then it will also reduce the production of these aerosols, which have a much shorter residence time in the atmosphere than the CO2. Fifthly, geoengineering could be a technical fix to sidestep the mitigation impasse. In particular, certain geoengineering technologies, in particular sulphate aerosol particle injection, seem to be enticingly cheap compared to restructuring the global energy system (Barrett, 2008). However, in much depends on the input assumptions in these economic analyses. A seventh reason for considering geoengineering is that it could prompt people into renewed mitigation efforts. The prospect of large-scale, perhaps poorly understood and scary science-fiction-like interventions in natural systems could be a way of inspiring policy makers and publics to redouble their efforts to achieve conventional greenhouse gas reductions. Indeed, this was Crutzen’s original aim (Pielke Jr., 2010, p125). A possible eighth reason is to change the climate to a desirable state. Some have suggested that geoengineering could be a means of “atmospheric restoration” (Jackson and Salzman, 2010). The term “restoration” implies that geoengineering could restore the climate to its pre-industrial condition. However, there is no scientific reason to prefer pre-industrial temperatures and geoengineering could be used to create a new climate, rather than simply ameliorate the effects of anthropogenic climate change or other "natural" warming. Finally, there is obvious commercial potential in the developing, construction and operation of the technologies required for geoengineering the climate. New intellectual property will undoubtedly be produced and entrepreneurial firms will be on the lookout to exploit commercial opportunities.

Although the motivations for pursuing geoengineering are varied and few, if any, are unproblematic, there nevertheless seems to be sufficient grounds to explore whether a safe, effective, and affordable means to ameliorate atmospheric warming and/or to achieve negative carbon emissions could be a desirable addition to the existing portfolio of climate policies consisting of conventional greenhouse gas mitigation and adaptation. However, at present, all such technologies are highly speculative and would require extensive research into their technical, environmental, socio-political, ethical and economic characteristics before their use could be sensibly contemplated.

What Should We Worry About?

Scientists and climate activists seem sharply divided over the wisdom and practicality of geoengineering. It is common for those engaged in geoengineering research to acknowledge that for many people, there is an "underlying feeling of abhorrence" (Keith 2000, p277) associated with the prospect. Experiments such as the Indo-German LohaFex project's ocean fertilisation trial and the SPICE project's proposed, but eventually cancelled, field trial of a sulphate aerosol delivery mechanism have already caused some controversy (see respectively Gross 2009; Brumfiel 2011; Cressey 2012). These controversies will only increase over time if research is allowed to continue – as it seems it will. Few argue that research should be stopped altogether (for a notable exception, see ETC Group (2009), even if they are concerned about the development of geoengineering technology (e.g. Jamieson, 1996; Gardiner, 2010).

Concerns are as varied as the technologies currently being considered. For some, goeengineering is symptomatic of humanity's hubris (Gardiner, 2010) or arrogance (Fleming, 2010) and a signal that the human attitude towards the natural world is seriously wrong. Other objections raise concerns about its effects on social justice and legitimacy. Prominent in most discussions has been the concern that even conducting research into climate geoengineering might encourage policy makers and publics to take a relaxed attitude towards efforts to reduce greenhouse emissions in the belief that geoengineering will provide a "get out of jail free" card. The idea that insurance against a risk can encourage continuation of dangerous behaviour is generally known as "moral hazard" (Baker, 1996). Another concern is that once research has started in earnest, there will always be pressure to undertake the next step. This might be due to pressure from funders and researchers, or cultural norms that are enthusiastic about technology and effectively hold if technology is developed then it should be used (Jamieson, 1996). This is the so-called slippery slope: research into conceptual framing and computer simulation and small scale experiments, will lead inexorably to large field trials and full-blown implementation.

Similar to the slippery-slope objection is the concern about the possibility of either social or a technical lock-in. Another concern relates to the possibility of either social or a technical lock-in. For example, stratospheric sulphate aerosol injection without complementary mitigation presents what has been called the *termination effect* (Shepherd et al., 2009, p35). If the programme is discontinued for any reason, the result would be a rapid rise in global temperature which could be harder to manage than any temperature increase that would have occurred without intervention. While there is no comparable technical lock-in with carbon removal technology – in principle, carbon-removal machines could be simply switched off– these are likely to require highly capital-intensive physical infrastructure, the sunk costs of which would create a vested interest in keeping them operational. This would create a social lock-in.

Turning to economics, some geoengineering technologies could be too costly and some could be too cheap. Mechanical air capture would seem to require considerable investment in physical infrastructure to capture carbon from ambient air and store it in spent gas wells or deep saline aquifers. By contrast, stratospheric sulphate particle injection is sometimes claimed to be cheaper than emissions reduction (Barrett, 2008; Bickel and Lane, 2008) although cost estimates vary widely according to input assumptions and are thus contested (see for example, Pielke Jr, 2010; Robock, 2009; Rickels et al., 2012). However predictions of low costs might encourage some to promote sulphate aerosol research over other measures. Moreover, if they are correct, sulphate aerosol particle injection might be cheap enough to be available more widely. This has led some commentators to worry that a single country or even an individual frustrated with the pace of climate negotiations might decide to act alone. David Victor (2008) has dubbed this the "Greenfinger" scenario. Another area of contention is the extent to which the private sector should be permitted to engage in geoengineering activities. Finally, arrangements must be made for redressing unwanted harms arising from the technology.

These considerations suggest that the issue of social control over the technologies is of great importance in deciding whether to proceed down the geoengineering pathway. Public resistance to new technology is rarely, if ever about the probability of death or physical injury from a technology (Rayner, 1987; Pidgeon et al., 1992; Slovic, 2000). Equally important is whether the institutions managing and regulating the technology enjoy public trust in their technical competence and integrity (Barber, 1983; Wynne, 1992; Poortinga and Pidgeon, 2003). Once this has been brought into question public confidence cannot readily be restored (Slovic, 1993).

To allay concerns such as those outlined above, there is a pressing need for a geoengineering governance regime. The Oxford Principles highlight the fact that the question of social control over geoengineering technologies will be key, and present core societal values that must be respected if geoengineering research, and any possible deployment, is to be legitimate. They also signal the need for various stakeholders to begin the process of ensuring that scientists, officials and politicians involved in development of geoengineering can be called to account. However, any geoengineering governance regime faces considerable challenges.

Challenges Of Geoengineering Governance

The key challenge of geoengineering governance is that articulated by the British sociologist, David Collingridge, as the "technology control dilemma" (1980). Briefly the dilemma consists of the fact that it would be ideal to be able to put appropriate governance arrangements in place upstream of the development of a technology to ensure that all of the stages from research and development through demonstration and full deployment are all appropriately organized and adequately regulated to safeguard against unwanted health, environmental and social consequences. However, experience repeatedly teaches us that it is all but impossible, in the early stages of development of a technology, to know how it will turn out in its final form. Mature technologies rarely, if ever, bear close resemblance to the initial ideas of their originators. By the time technologies are widely deployed, it is often too late to build in desirable characteristics without major disruptions. As Collingridge put it:

> Attempting to control a technology is difficult, and not rarely impossible, because during its early stages, when it can be controlled, not enough can be known about its harmful social consequences to warrant controlling its development; but by the time these consequences are apparent, control has become costly and slow. (1980, p19)

The reasons why a developing technology becomes entrenched include: the presence of complementary technological developments, the costs of withdrawing it, or because those involved in its development feel a personal commitment to it and will lose face by admitting that (in some respect) their project has failed.

Recognition of the control dilemma has led to calls for a moratorium on certain emerging technologies and, in some cases, on field experiments with geoengineering. This would make it almost impossible to accumulate the information necessary to make informed judgements about the feasibility or desirability of the proposed technology. However, Collingridge did not intend identification of the control dilemma to be a counsel of despair. He and his successors in the field identify various characteristics of technologies that contribute to inflexibility and irreversibility and which are therefore to be avoided where more flexible alternatives are available. These undesirable characteristics include high levels of capital intensity, hubristic claims about performance, and long lead times from conception to realization, to which the United Kingdom's Royal Commission on Environmental Pollution recently added, in the context of nanoparticles, "uncontrolled release into the environment" (RCEP 2008, p8). Consideration of the control dilemma suggests that, other things being equal, it might be sensible to favour technologies that are encapsulated rather than involving dispersal of materials into the environment and those that are easily reversible over those that imply a high level of economic or technological lock-in.

The other key challenge for geoengineering governance lies in the varying degrees of international agreement and coordination that would seem to be required for (or, indeed, already apply to) the different technologies involved.

Existing Attempts To Regulate

Absent from the current legal landscape is a single treaty or institution addressing *all* aspects of geoengineering; rather, the legal picture, both nationally (Bracmort et al., 2010) and internationally (Redgwell, 2011), is a diverse and fragmented one. The Royal Society suggests that many issues of international coordination and control could be resolved through the application, modification and extension of existing treaties and institutions governing the atmosphere, the ocean, space and national territories, rather than by the creation of specific new international institutions.

The current international legal framework which might regulate geoengineering, includes hard and soft law, key treaty instruments and customary law norms. Some instruments can apply to both transboundary CDR (e.g. ocean fertilisation) and SRM methods. Others will be more pertinent to CDR or SRM only. Notwithstanding the applicability of the following instruments, there are currently many gaps in regulation, most obviously with respect to the regulation in areas beyond national jurisdiction of SRM methods. None of the instruments below were designed to regulate geoengineering and none can be regarded as a one-stop shop. This is due (a) to their stated goals (b) their regional, rather than global scope, (c) their applicability to only SRM or CDR technology, or all three.

Firstly, it should be noted that the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and its 1997 Kyoto Protocol (KP) make no explicit reference to geoengineering nor have the Parties expressly considered it. Nonetheless, certain provisions are indirectly relevant such as the promotion of scientific cooperation and the general obligation to use appropriate methods, e.g. impact assessments, to minimise adverse effects on the quality of the environment. The UNFCCC and KP create a significant institutional structure for governance of the climate regime, which could include some geoengineering techniques. However, the UNFCCC does not explicitly govern research, while the KP is due to expire in 2013, therefore there is some uncertainty about the regime's future. However, there are other environmental treaties which are likely to be relevant.

Treaties of application to both SRM and CDR methods the 1977 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques Convention Environmental Modification, which is a rare example of a binding treaty instrument specifically addressed to environmental modification. It prohibits military or any other hostile uses of environmental modification having widespread, long-lasting or severe effects, while expressly permitting peaceful use consistent with other applicable rules of international law. ENMOD's chief importance lies in its prohibition upon hostile uses of climate modification, and in the explicit encouragement for their peaceful uses. It does not does not deal with the question whether or not a given use of environmental modification techniques for peaceful purposes is in accordance with generally recognized principles and applicable rules of international law. That said, as the only international instrument directly to regulate deliberate manipulation of natural processes having "widespread, long-lasting or severe effects", ENMOD offers one possible route for prohibition of large-scale geoengineering experimentation and deployment pending the development (likely elsewhere) of appropriate governance mechanisms.

With respect to CDR technologies, regulation of ocean iron fertilisation is already underway under the 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter and 1996 Protocol (LC/LP). Early field trials of ocean iron fertilization led to a 'statement of concern' being issued by the Scientific Bodies to the global 1972 London (Dumping) Convention (LC) and 1996 London Protocol (LP), endorsed by the Parties in 2007. A year later, the Parties adopted a resolution agreeing that ocean fertilization is governed by the treaty but that legitimate scientific research is exempted from its definition of dumping. However, pending the drafting of an assessment framework to be developed by the

Scientific Groups under the London Convention and Protocol, States are urged to use the "utmost caution and best available guidance" when considering scientific research proposals. This expression of caution is a reflection of the application of the precautionary approach which the 1996 London Protocol both defines and requires the Parties to apply. In addition, the resolution also sets down a marker that ocean fertilization activities apart from legitimate scientific research "should not be allowed", are not exempted from the definition of dumping, and "should be considered as contrary to the aims of the Convention and Protocol". The effectiveness of national enforcement of the London Convention and Protocol has recently been called into question after a group led by Russ George, the former director of the Planktos dumped 100 tonnes of iron into ocean waters west of the Haida Gwaii islands in north-west Canada. George presented the activity as an attempt to restore salmon to that part of the ocean, but this controversy has simply confirmed George's status as a "rogue geoengineer" (Corner, 2012; for an account of George's previous controversial activities, see Kintish, 2010). The Canadian government has launched an investigation.

The 1992 Convention on Biological Diversity was initially invoked in the controversy surrounding field trials of ocean fertilisation, a CDR technique. The Parties debated adopting a moratorium on all ocean fertilization activities but ultimately followed the London Convention approach, if not its language. States parties are urged to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities and a "global transparent and effective control and regulatory mechanism is in place for these activities'" An exception is made for small-scale research studies within "coastal waters" for scientific purposes, without generation or selling of carbon offsets or for any other commercial purposes. Given that "coastal waters" is ambiguous, and that small-scale near-shore studies are meaningless for ocean fertilization field trials, the negative impact this step could have on scientific research led to a swift response by the Intergovernmental Oceanographic Commission's Ad Hoc Consultative Group on Ocean Fertilization drawing attention both to the need for clarification of the language of the COP decision and challenging the scientific assumptions underpinning it.

In 2010 the Parties to the CBD addressed all geoengineering activities. It was decided, in line with the decision on ocean-fertilization, that "no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment".

With respect to SRM technologies, the currently existing instruments mostly apply to stratospheric aerosol injection. Where injection takes place from ships, or the impacts of injection are felt in the marine environment, the rules relating to the law of the sea will apply. The most relevant instrument is the 1982 Law of the Sea Convention (LOSC). It is in many major respects also considered to reflect customary international law which binds all States. Coastal States exercise jurisdiction over their maritime zones and all States have jurisdiction over vessels flying their flag. This would not permit "launch" of aerosols from foreign-flagged vessels in the 12-mile territorial sea without the express consent of the coastal State. Within the exclusive economic zone (EEZ), all States enjoy freedom of navigation in the zone, so ocean fertilisation, even without consent of the Coastal State, would be permissible. On the high seas, beyond the 200-mile EEZ, there is a general requirement to have due regard to the interests of other States in the exercise of their high seas freedoms including most pertinently here freedom of over-flight, to protect and preserve the marine environment

(Article 192 LOSC) and to take steps, individually or jointly, to prevent, reduce and control the pollution of the marine environment from any source. If stratospheric aerosols would have deleterious effects on the marine environment; such provisions are clearly applicable.

Above the oceans, there is no global instrument comparable to the LOSC which governs the atmosphere. The injection of stratospheric aerosols is thus subject to the jurisdiction and control of the sovereign in whose air space it is injected and/or the state of registration of the aircraft, and may have further constraints if the effects cause pollution to other States or to common spaces. In addition the 1979 Long-range Transboundary Air Pollution Treaty for Europe and North America (LRTAP) has a number of protocols addressed to the control and reduction of certain pollutants into the atmosphere, sulphur emissions, and has evolved a compliance mechanism to address breaches of the provisions of the protocols. Of course the purpose of LRTAP is not to regulate SRM techniques but rather to address acidification from sulphur deposits created mainly by industrial sources and the burning of fossil fuels. Nonetheless, to the extent that geoengineered processes contributed to exceeding fixed national emissions ceilings, LRTAP could be implicated especially if the substances placed in the atmosphere constitute "air pollution". At present, there is only an obligation to exchange information. Of course, it is always open to the parties either to amend an existing Protocol or add a further protocol addressing, and perhaps prohibiting, injected substances or activities. However, treating SRM techniques as "pollution" for these purposes falls short of the comprehensive legal regulation likely required. Moreover, LRTAP is a regional Economic Commission for Europe instrument and does not have the capacity to transform into a multilateral instrument. Should one of the effects of stratospheric aerosols be to increase ozone depletion, its injection could constitute breach of the obligation to protect the environment against human activities which modify, or are likely to modify, the ozone layer, an obligation found in the 1985 Convention for the Protection of the Ozone

Layer. The overall objective of the ozone regime is to eliminate ozone depleting substances. Like LRTAP, this Convention has a well-developed compliance procedure, established pursuant to the 1987 Montreal Protocol, to address non-compliance with obligations of an *erga omnes* character where breach results in further harmful depletion of the ozone layer. It requires States Parties "to take appropriate measures in accordance with [its provisions] to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer", and take steps to prevent anthropogenic sources of modification including "hydrogen substances", "water" and various other substances. The applicability of this Convention will turn on the "adverse effects" and the scope of regulated substances.

A Flexible Architecture

What might a governance architecture look like if constructed with the control dilemma in mind? Ideally it would cover the entire process from computer modelling through to possible implementation. It would embody broadly shared societal values designed to ensure trustworthiness and transparency. It would have to be sufficiently broad to cover a wide range of technically diverse options. It would need to ensure monitoring and evaluation at critical stages in the research, development and application of specific geoengineering technologies. It would be capable of distinguishing between activities with potential transboundary impacts and those that do not. Ideally it would make use of existing institutions wherever possible and require a minimum of new international instruments. Precedent suggests that negotiation of such instruments would be a complex and protracted process.

Effective governance of technology requires adequate management of risk and consideration of its perception by potentially affected parties. As noted earlier, public perception of risk is as much (if not more) about questions of values and social justice the probability of death or physical injury. For example voluntary risk is generally seen as more acceptable than where it is imposed involuntarily. Therefore the issue of whether the affected public believes that it has been given the opportunity to give or withhold consent is particularly important. Another example is that some technologies prompt a negative affective response, or 'dread' (Slovic, 2000) and others do not. An early piece of public opinion research on geoengineering in the UK concluded that participants exhibited a preference for the technologies that they regarded as "natural" and were against technologies that the perceived as "unnatural" (National Environmental Research Council (NERC), 2010). To manage the risks of geoengineering technology in this fullest sense, a governance architecture would have the power to impose conditions or delays on research or implementation projects in response to public concerns, including concerns about values and social justice, until those concerns are addressed.

Given the heterogeneity of the technologies under consideration and their highly uneven states of development, it is probably not constructive to generate public debate about the effects of an imaginary technology. However, it is possible to interrogate the visions, optimistic and pessimistic, of what is plausible and desirable and what are the envisaged impacts on society. Therefore, a promising approach would seem to be that of adopting an *ex ante* set of high-level principles of broad application and the requirement that any specific geoengineering project embody specific protocols to ensure that each principle is adequately addressed at each stage of development. The principles should probably be few in number, easy to remember, and establish the key societal goals and concerns, the "non-negotiables", for geoengineering. The more-flexible technology-specific "research governance protocols" would then take account of the characteristics and stage of development of a particular technology. The idea behind these principles is that they should provide real assurance that the entire process from initial research through development, field trials, and eventual deployment are conducted openly and in the public interest of all affected countries, while also allowing for the development of more flexible technology-specific protocols for the governance of individual geoengineering approaches as their technical contours and socioeconomic implications become clearer through the R&D process.

The Oxford Principles

The original text of the Oxford Principles is reproduced below. The five Principles have equal status: numbering does not imply priority.

- Principle 1: *Geoengineering to be regulated as a public good.*
  While the involvement of the private sector in the delivery of a geoengineering technique should not be prohibited, and may indeed be encouraged to ensure that deployment of a suitable technique can be effected in a timely and efficient manner, regulation of such techniques should be undertaken in the public interest by the appropriate bodies at the state and/or international levels.

- Principle 2: *Public participation in geoengineering decision-making.*
  Wherever possible, those conducting geoengineering research should be required to notify, consult, and ideally obtain the prior informed consent of, those affected by the research activities. The identity of affected parties will be dependent on the specific technique which is being researched – for example, a technique which captures carbon dioxide from the air and geologically sequesters it within the territory of a single state will likely require consultation and agreement only at the national or local level, while a technique which involves changing the albedo of the planet by injecting aerosols into the stratosphere will likely require global agreement.

- Principle 3: *Disclosure of geoengineering research and open publication of results.*
  There should be complete disclosure of research plans and open publication of results in order to facilitate better understanding of the

risks and to reassure the public as to the integrity of the process. It is essential that the results of all research, including negative results, be made publicly available.

- Principle 4: *Independent assessment of impacts.*
  An assessment of the impacts of geoengineering research should be conducted by a body independent of those undertaking the research; where techniques are likely to have transboundary impact, such assessment should be carried out through the appropriate regional and/or international bodies. Assessments should address both the environmental and socio-economic impacts of research, including mitigating the risks of lock-in to particular technologies or vested interests.

- Principle 5: *Governance before deployment.*
  Any decisions with respect to deployment should only be taken with robust governance structures already in place, using existing rules and institutions wherever possible.

(Rayner et al., 2009).

The text of the Oxford Principles was preceded by a short Preamble, which outlined the basic rationale for engaging in geoengineering research. The Preamble also noted the need for continued efforts in mitigation, the heterogeneity of the technologies under consideration and the fact that there might be "governance gaps", hence the need to consider governance issues.

The Intentions Behind The Oxford Principles

The Oxford Principles are proposed as a draft framework to guide the collaborative development of a system of geoengineering governance, from the earliest stages of research, to any eventual deployment. Principle 5, "Governance before deployment" does not advocate eventual deployment, but simply indicates that any decision about whether or not to deploy must be made in the context of a strong governance structure. As few presuppositions as possible are made: the main ones being: 1) at least some research into geoengineering should take place and 2) research and any deployment must be subject to governance. Within these broad parameters, the intention was to call for an open debate about what a geoengineering governance regime should look like. There are at least two aspects to this question. First, what are the values that should guide a governance regime? Second, what operational features of a governance regime are desirable and how might one be constructed? The original memo to the Select Committee focused on the first question. The authors intended that the submission of the Principles would serve as a starting point of a discussion between policy-makers, scientists, civil society groups and citizens about the key overarching societal values that should be embodied in a geoengineering governance system. In this discussion, some Principles might be reformulated. Some principles might be replaced, or perhaps the original five principles might be supplemented.

Proposing a set of governance principles naturally invites questions about their implementation. The Oxford Principles were intended to guide a flexible governance architecture, operating at different levels, and involving formal and informal mechanisms, depending on the stages of research and the issues raised by a particular technology. Their institutional implementation will, moreover, help specify their content in greater detail. The authors believe that even in the very earliest stages of geoengineering research, it is imperative to begin proper consideration of what a flexible governance architecture should look like and consider how to build it in a bottom-up, collaborative process. It is also appropriate to consider how existing institutions might be adapted and integrated into a geoengineering governance system.

The Function Of The Oxford Principles

It is immediately obvious that the principles are high-level and abstract. They should be regarded as akin to principles in the legal sense: as laying down the basic parameters for decision-making. Like legal principles, for example the principle of *due process* in both international and domestic law, they do not make concrete recommendations but must be interpreted to fit a particular case. The absence of specific action-guiding prescriptions was one criticism of the Oxford Principles expressed in a recent Nature editorial (Nature 2012, p415). However, the other sets of principles that have been proposed in relation to geoengineering are similarly high-level and abstract. Nor is this disadvantageous. Given the heterogeneity of proposed geoengineering methods and the varying degrees of development, it is undesirable, if not impossible, for the Oxford Principles, or any other sets of principles, to be anything but high-level. A "one-size fits all" approach is certainly not appropriate. The authors of the Oxford Principles intended them to be interpreted and implemented in different ways, appropriate to the technology under consideration and the stage of its development as well as the wider social context of the research. What matters is that at each stage of research, researchers should be able to give a coherent account of how they interpreted and followed the Oxford Principles in their particular piece of research. As such, the Principles specify the ways in which those engaged with geoengineering might be called to account. In this, as well as being broadly analogous to high-level legal principles, they are similar to the codes of conduct used in many professions. For example, there will be many contextual factors in determining whether a physician has acted negligently, but the fact that not all of them will be specified in advance does not mean that there is no need for a principle against clinical negligence. To the contrary, most people would be rather concerned if there were not.

Indeed, the medical world provides us with a partial analogy in the Belmont Principles (which as noted earlier have inspired one set of principles for geoengineering research). These three principles, *respect for persons*, *beneficence* and *justice* (National Commission for the Protection of Human Subjects of Biomedical and Behavioural Research, 1979) are also high-level, rather than directly action-guiding. Some prefer to describe them as embodying an *ethos* (Gabriele, 2003). Commentators recognise that the precise meaning of the Belmont Principles is "closely bound up with the changes in medicine and the social context in which medicine is practised" (Cassells 2000, p13) and that they must be re-interpreted in order to remain relevant as society changes over time. While the Belmont Principles were never formally embodied, or even endorsed by the US government, they are nevertheless influential, being a reference point for the institutional review boards which sanction research proposals. As each of the key values behind the Belmont Principles required elaboration, which was done in the text of the Belmont Report, it is appropriate here to elaborate on the societal values expressed in the Oxford Principles.

The Societal Values Behind The Oxford Principles

Each of the Oxford Principles was intended to capture a widely held societal value that should be respected in the development of all geoengineering technologies.

Principle 1: Geoengineering to be regulated as a public good.
The first principle acknowledges that all of humanity has a common interest in the good of stable climate (we might invoke the idea that climate change is a common concern of humankind) and therefore the means by which this is achieved. It suggests that the global climate must be managed jointly, for the benefit of all, and with appropriate consideration for future generations. In short, geoengineering must be regulated so as to promote the general good.

Specifying exactly what counts as "the benefit of all" requires consideration of global and intergenerational justice. For example, must everyone benefit equally from the development of geoengineering technology? Or should the notion of Pareto-optimality be invoked: benefits can vary, but no-one must be rendered worse off overall? An alternative (and weaker) interpretation is the Kaldor-Hicks criterion which holds that some can be rendered worse off provided that compensation is in principle payable to them, but does not require that compensation is actually paid. Other interpretations are no doubt available. Considerations of distributive justice should serve as a partial guide to geoengineering research priorities, for example, technologies which have greater potential to be of benefit to all (perhaps especially to the most vulnerable), should arguably be at the top of the list. Moreover, if the global climate is a common concern of humankind, then it would be wrong for a few states to hinder the development of a regulatory system that would ultimately be of benefit to all. Invoking the idea of the common concern of humankind could thus provide a normative foundation for requiring states' compliance with an international geoengineering governance regime, regardless of whether they have registered objections.

In highlighting the core value that all of humankind has a common interest in the good of a stable climate, Principle 1 also points to the need to be watchful for developments that could undermine it. The granting of patents, the distribution of intellectual property rights can result in, or exacerbate existing, injustices. This issue was highlighted in a second memorandum from the Oxford Principles authors (Kruger et al., 2009), submitted after some Select Committee witnesses raised questions about Principle 1. There should therefore be a presumption against exclusive control of geoengineering technology by private individuals or corporations.

However, this does not rule out a role for the private sector in geoengineering, just as t**he public goods character of national defence does not preclude the participation of the private sector in its provision. Indeed, the firms that develop and manufacture defence technology are frequently the repositories of essential technical**

knowledge, skills and experience that is unavailable from any other source. This may also prove to be the case in the development of geoengineering technologies. However, the private contractors in the defence sector are precluded from selling the technologies or intellectual property that they have developed for governments to foreign powers or other parties, unless the contracting government deems it to be in the public interest to do so. Governments control the terms of supply of the technologies in the interests of their citizens. In other words, while the involvement of the private sector in the delivery of a geoengineering technique should not be prohibited, and may indeed be encouraged to ensure that deployment of a suitable technique can be effected in a timely and efficient manner, regulation of such techniques should be undertaken in the public interest by the appropriate bodies at the appropriate level of governance (local, national, and/or international). The provision of public goods at the global level will inevitably raise issues of international coordination – but these are not insurmountable as examples of successful international technological co-operation, such as air traffic control and management of Antarctica, illustrate. Therefore, whilst Principle 1 does not mean that there can be no intellectual property in geoengineering, it highlights that there might be a need for restrictions to ensure fair access to the benefits of geoengineering research. In some cases, this might result in a refusal to patent (as happened with the Human Genome Project) but we need not expect this to obtain universally.

Principle 2: *Public participation in geoengineering decision-making.*
There are three reasons typically advanced in favour of public participation with new or emerging technologies such as geoengineering. First where risks may impact external parties, the right thing to do is to include them in any decision process which may ultimately affect them. A second reason is that participation can also it lead to better decision-making through inclusion of a wider range of information, perspectives and values

can be brought to attention of decision-makers. Thirdly, there is an instrumental reason: consent provides a social license to operate. Institutions with responsibility for taking decisions about risk have not always enjoyed full public confidence. Lack of mechanisms for lay participation in decision-making in geoengineering will further undermine public trust (Fiorino, 1990; Dowling et al., 2004, Stirling, 2008).

Principle 2's requirement of public participation is based on the first, normative, reason. It is an appeal to the value of legitimacy. The explanatory text effectively contains an appeal to the "all affected principle", that those affected by a decision should have a say in its making (Whelan 1983). Implementation of this principle requires specifying the way in which someone must be affected to have a say in a decision. Should it be limited to material effects, or should cultural and moral beliefs also count? Those who believe that even to consider geoengineering is a morally corrupt offence against nature or the thin end of the wedge that will develop its own momentum leading inevitably to implementation might reject the idea that only those populations immediately and materially connected with any stage of activity should participate in the decision making process. However, interpreting "affectedness" in terms of having one's cultural or moral beliefs challenged would potentially enlarge the constituency, making the decision-making process less manageable. One way of addressing this might be question whether active consent is necessary at all stages of the research process. Perhaps here, the principle should be weakened so that decisions must be justifiable to those affected, or that those affected should be consulted, rather than requiring active consent from them.

Should the scale and location of geoengineering activities extend from computer simulations and laboratory experiments to outdoor experiments, limited field trials, and large-scale field trials, the net should be cast wider, the level of participation deepened and the degree of social control raised, as more people stand to be affected in at least the material sense. Justice in siting is an important concern arising with most technological developments. Technologies which are potentially hazardous to the environment and to human health have often been tested or installed in the most disadvantaged areas within a state (Schrader Frechette, 2002). There is also a history of "exporting hazards" (Shue, 1981) from developed to developing countries. It would be wrong for the relatively disadvantaged to be further disadvantaged by the testing of geoengineering technology. Thus consideration should be given to the views of all who might be directly and materially affected by any proposed outdoor experiments.

There is a question of whether any group of people should be able to veto research, for example, of a geoengineering field test, and more generally how meaningful global participation in decision-making could be secured (Virgoe, quoted in House of Commons 2010, ev12). It is not possible or desirable, in advance, to determine if this is appropriate. Differences in political and legal cultures will shape the mode and extent of public participation around the world. Different ideas about democracy and the relationship of between individuals and society will engender different understandings of consent. In some contexts, revealed consent through behaviour in the marketplace may be acceptable, while in others people will only expect explicit informed consent. In yet others, hypothetical consent may be used whereby the decisions of an authority whose legitimacy is accepted are deemed to be consented to regardless of whether or not individual citizens like those decisions (Rayner and Cantor, 1987). Principle 2 thus does not (and should not, in deference to cultural differences) specify exactly what measures must be taken to secure public participation. Rather it highlights the need to develop them alongside the technological research being pursued.

P**rinciple 3*****: Disclosure of geoengineering research and open publication of results.***

This principle requires the prompt and complete disclosure of research plans and open publication of results. There are pragmatic reasons and normative reasons to value transparency. Pragmatic considerations include epistemic value and trustworthiness. Knowing the results of all geoengineering research ought to allow better decisions to be made about whether and how to proceed. With regard to trustworthiness, the House of Lords Science and Technology Committee's *Science and Society Report* (2000) concluded that openness and transparency are a fundamental precondition for maintaining public trust and confidence in areas which may raise controversial ethical or risk issues. The normative reason to value transparency is that it is one aspect of respecting people. Even if one does not have a direct say over any particular matter, to be informed of decisions is an acknowledgement of one's moral status. Without transparency, 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.

The requirement of transparency applies to all kinds of research results including those from computer simulations and modelling as well as empirical research. Mindful of some well-publicised cases where pharmaceutical companies withheld negative results of product trials in seeking licences (McGoey, 2009; McGoey and Jackson, 2009), this principle also holds that the results of *all research* be made publicly available. Nor should there be "national security" exceptions.

Disclosure does have risks: malign agents could use the information to develop technologies for their own ends. Such "dual use" concerns abound in the life-sciences. A recent case is the publication of two articles describing a mutation of the H5N1 avian flu virus in *Nature* and *Science*. The US National Science Advisory Board for Biosecurity (NSABB) initially recommended that key information about the studies' methods and results be removed , citing concerns that the developed strains could be used by bioterrorists or accidentally released (Yong 2012, p14). However, in the face of controversy, NSABB eventually decided that publication of revised papers (but which included the full methods and results) would better serve the public interest, citing "new and clarified information in the manuscripts, additional perspectives provided by influenza biology experts, highly pertinent but as yet unpublished epidemiological data, and relevant security information" (Collins, 2012). There is much more that can be said on this issue, but it seems premature to conclude that concerns about dual-use should trump a commitment to transparency and full disclosure, and the burden of proof should fall on the advocates of any restriction.

Principle 4: Independent assessment of impacts.

Regular assessments of the impacts of geoengineering research should be conducted by a body independent of those undertaking the research. Depending on the kind of technology and the stage of development, such assessments might be conducted by research organizations and funders, regional or national governments, or through international bodies if techniques potentially have transboundary impacts. Assessments should address both the environmental and socio-economic impacts of research, including mitigating the risks of lock-in to particular technologies or creation of vested interests. Risk-free research is impossible, but efforts can be made to assess whether the risks are reasonable, i.e. the potential magnitude of effects, whether the risks can be reduced, whether the information can be gained by other means, and whether the value of the information is worth the risk (Savulescu, 1998). Such integrated assessments have the potential to include risk reduction requirements and should feed into public engagement work. They could also provide a basis for establishing liability for undesirable side effects.

An assessment of impacts is required so that the risks and possible outcomes of conducting research into geoengineering are identified and put to public deliberation (see principle 2). The basic value behind this principle is that of a *duty of care.* A duty of care is a norm embodied in many professions, acknowledging that their clients have legitimate expectations regarding their conduct (some of which might be independent of any final outcome). Likewise, the principle of independent impact assessment acknowledges that scientists have responsibilities to ensure that carrying out their research does not negligently harm persons or a local environment. Their responsibilities also pertain to causing harm indirectly, e.g. by being part of a project that ultimately causes social or political problems. This is not to say than individual scientists or engineers can be blamed or held liable for all the abuses of their work. However, they ought to be encouraged to be aware of the wider ramifications of their research.

The need for independence is clear: to ensure that the assessment is impartial and unbiased. At least three issues arise. First, how should a review body be composed to ensure that it is independent? Is it sufficient that its scientific members declare interests, or should it include at least some lay people? Second, before an assessment is made a decision has to be taken on what kinds of impacts are to be included in the assessment (recall Principle 2). Third, when can the duty of due diligence be satisfied? How much time and effort has to go into the investigation of impacts before research can proceed? Again, at this early stage, it is possible only to highlight the questions that are likely to arise rather than to give specific answers.

In the process of implementation, it would be appropriate to consider how a duty of care has been developed in other areas, the variety of impacts, including both environmental and social impacts, to be assessed and the appropriate levels of action required to prevent or minimise any considered to be adverse. Keith et al. (2010) suggested a "blue-team" and "red-team" format in which one group of researchers tries to develop the technology while another team searches for its flaws. This is a common strategy in building secure computer systems, in the military, airport security and, in the USA, some government organisations and NASA. Studies of the organisational culture and structures of “high reliability organisations” (e.g. LaPorte 1996, pp63-65) could provide guidance for developing an appropriate culture in research institutions and for setting up the independent review bodies.

Principle 5: *Governance before deployment.*

The fifth principle is intended to addresses the transition from geoengineering research to deployment. The boundary is fuzzy: an experiment that could determine the efficacy of some techniques would have to be of such scale and duration that it would amount to deployment. During any such large-scale test, it would be likely that an unusual weather event, for example, something similar to the Pakistan floods of 2011, would be blamed on the test.

Therefore the fifth principle highlights the need for an overarching governance structure to be present before any decision to deploy is made. Whereas the governance process may be built largely or even entirely on existing institutional and legal arrangements for the management of scientific research, some geoengineering techniques, especially those with transboundary impacts might require new explicit international agreements, or reforms of global governance institutions. The need for accountability is justified by the fact that all humanity has a stake in how the global climate is managed, expressed in Principle 1, and the basic value of legitimacy expressed in Principle 2. Ultimately it is predicated on the basic value that *no person should be subjected to arbitrary power.* When a person is unable to exit an institutional set-up, respect for him as an autonomous agent requires that he can hold it to account: that its existence and decisions are justifiable. Justifications of deployment decisions will most likely appeal to the basic societal values expressed in the earlier four principles and perhaps others. Governance structures should also provide mechanism to appeal decisions and a mechanism for compensating those who are made worse off by any decision to deploy geoengineering. Finally, they must also have credible capacity to enforce rules and terminate activity in the event that unanticipated deleterious effects result.

Future Directions

If the Oxford Principles are to be of any practical value, attention must be paid to how they are to be implemented. As noted earlier, any geoengineering governance system must fact the technology control dilemma. The way to overcome this dilemma is to build in flexibility into geoengineering governance from the outset. It is likely that an incremental, bottom-up process, guided by values and mindful of problems such as the control dilemma will best deliver it. It is therefore envisaged that the Principles will form part of a flexible architecture for geoengineering governance, which will eventually be realised across different types of formal and informal institutions. They can be used to shape a culture of responsibility among researchers, guide self-regulation from the bottom-up or they can be used to formulate statutory requirements imposed from the top down. Different forms of institutionalisation may be appropriate depending on the level of technological development and its predicted effects. A legal regime regulating computer simulations of stratospheric sulphate particle injection would be regulatory overkill. Conversely, voluntary regulation of large-scale field testing seems to be inadequate. Existing formal and informal mechanisms might have to be invoked or adapted, or new mechanisms designed to ensure that the governance architecture is capable of adequate monitoring and evaluation at critical stages in the research, development and demonstration (RD&D) of geoengineering technologies. It should also be able to cover a wide range of technically diverse options and distinguish between technologies with potential transboundary impacts and those without.

It is increasingly recognised that a multi-scalar and multi-level governance architecture is needed to combat climate change successfully (Osofsky, 2009; Scott, 2011). The same will most likely be true of geoengineering.

Indeed, the main values of multi-scalar governance, namely: 1) the participation of multiple parties; 2) the use of a range of instruments; and 3) an emphasis on multiple levels of governance (Scott 2011) appear consonant with the Oxford Principles.

Towards Implementation

The key to implementation of the Oxford Principles is the development of research protocols for each stage of the development of the technology from the initial idea through computer simulation, laboratory experiments, outdoor experiments, field trials, to any implementation. Before any activity, researchers should be required to prepare a protocol explicitly articulating how the issues embodied in each of the Oxford Principles is to be addressed, to be interrogated by a competent third party as a part of a stage-gate process. The review body at each stage-gate must be invested with the authority to withhold approval until it is assured that the experimental design for that stage satisfies the Oxford Principles and that it will be competently and conscientiously implemented. Further fleshing out of the criteria for assessment at various stage gates may come from external bodies. An example is the initial and full environmental assessment criteria contained in the Assessment Framework for Scientific Research involving Ocean Fertilization adopted by the Contracting Parties to the London Convention/Protocol. These are to be used by national decision-makers as a tool for assessing proposed activities, on a case-by-case basis, to determine whether the proposed activity is legitimate scientific research compatible (Assessment Framework, 2010). The identity of the reviewing parties will be appropriate to the stage of research. University ethics committees might be able to provide sufficient review for computer modelling. Outdoor experiments might require a higher level of review which could be provided by the public funding bodies that sponsor the research, or by independent review panels appointed for the purpose. There are examples of blending of these roles, such as the EU step-by-step approvals process for GMOs, which combines the provision by an expert body of independent scientific advice at the environmental assessment stage, with legal authorisation by the Commission and Member States. Where an experiment has the potential for transboundary impact, clearly the review should include representatives from all potentially affected countries. Where there is a risk to third parties, the review body could use the stage-gate process to specify risk-reduction requirements and possibly even help establish satisfactory liability arrangements in anticipation of potential damage. Most importantly, each stage-gate would enable researchers and regulators to address specific issues of reversibility. A stage-gate method of governance was used in relation to the SPICE project's proposed test-bed, and the test-bed was postponed in order that further stakeholder engagement could be conducted (Macnaghten and Owen, 2011; for an account of the public engagement method and results see Pidgeon et al., 2013). While the test bed was ultimately cancelled for different reasons, the stage-gate process was easily implementable and served its intended purpose well.

The development of technology specific research protocols is the first step of the bottom-up process of building a flexible governance architecture. Through the development of the protocols, the Principles will be translated into specific content, recommendations and regulations, appropriate to different technologies as they develop. For example, they could serve initially as a code of conduct by scientific researchers and research councils. The more specific regulations generated in the research setting could then be adopted and modified by other institutions, including, where necessary, formal mechanisms such as legal regulation.

Conclusion

Geoengineering research could be of great benefit if it contributes to averting climate impacts that stand to have significant effects on millions of lives. However the development of a technology powerful enough to manipulate the global climate has as much potential to exacerbate existing inequalities as it does to ameliorate them. At the time of writing, it is unclear how governance of climate geoengineering will be taken forward. However it is clear that scientific momentum is building behind efforts to develop geoengineering options and that legislators are seeking guidance on how research should be conducted and how decisions about deploying any resulting technology should be made. In that spirit, the authors of the Oxford Principles invite further efforts from all parties to refine the existing principles and review their adequacy and completeness as well as to develop specific research protocols and stage-gates for existing and proposed research projects.

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Figures and Tables.

IPCC EMISSIONS SCENARIOS

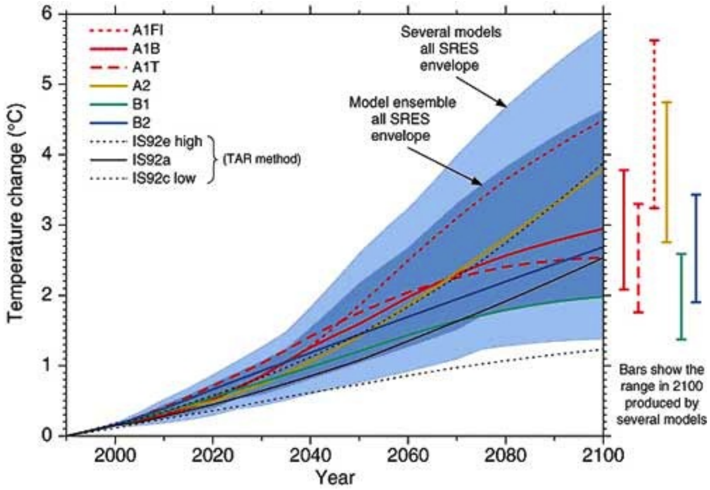

Figure 1 (IPCC, 2007).

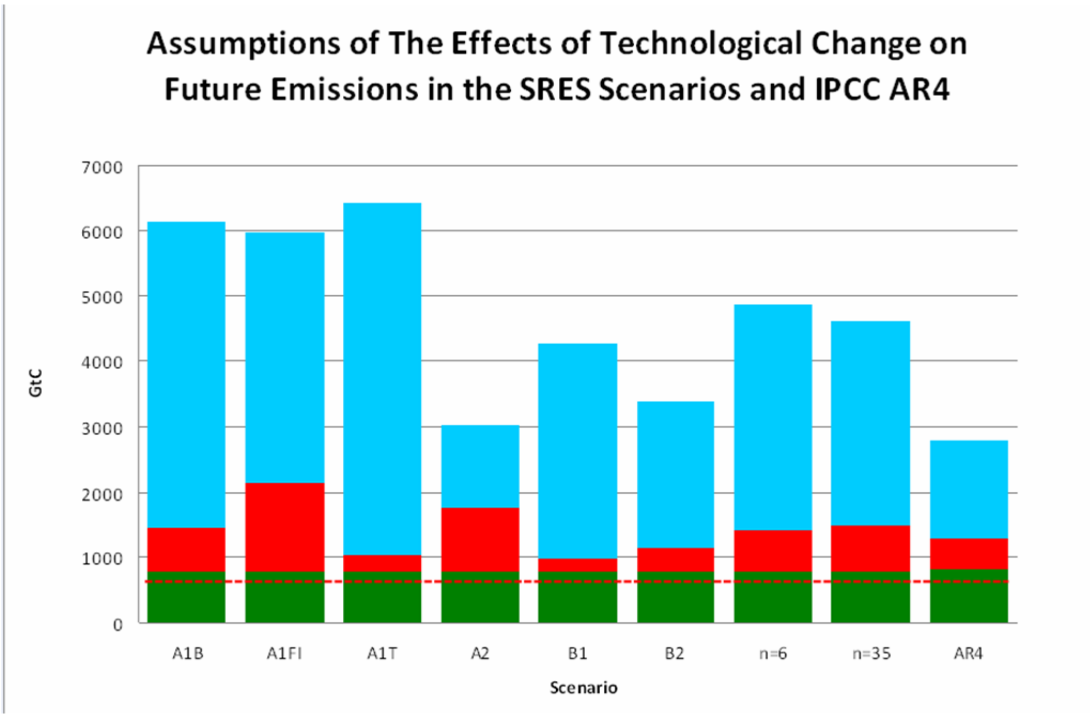

Figure 2 (Source: Pielke Jr et al., 2008).

	CARBON DIOXIDE REMOVAL	SOLAR RADIATION MANAGEMENT
ENVIRONMENTAL SYSTEMS ENHANCEMENT	OCEAN IRON FERTILIZATION	STRATOSPHERIC AEROSOLS
BLACK BOX ENGINEERING	AIR CAPTURE (ARTIFICIAL TREES)	SPACE REFLECTORS
	CARBON DIOXIDE REMOVAL	SOLAR RADIATION MANAGEMENT
ENVIRONMENTAL SYSTEMS ENHANCEMENT	OCEAN FERTILIZATION	STRATOSPHERIC AEROSOLS
TRADITIONAL “BLACK BOX” ENGINEERING	AIR CAPTURE	SPACE REFLECTORS

Table 1. A categorisation scheme for geoengineering technologies.