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The Oxford Principles

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Abstract Scientific momentum is increasing behind efforts to develop geoengineering options, but it is widely acknowledged that the challenges of geoengineering are as much political and social as they are technical. Legislators are looking for guidance on the governance of geoengineering research and possible deployment. The Oxford Principles are five high-level principles for geoengineering governance. This article explains their intended function and the core societal values which they attempt to capture. Finally, it proposes a framework for their implementation in a flexible governance architecture through the formulation of technology-specific research protocols.

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1 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, organizations who have called for increased research into geoengineering include: the Institute of Mechanical Engineers (2009) and the House of Commons (2010) in the UK; Novim (Blackstock et al. 2009), the Government Accountability Office (2010), the Congressional Research Services (Bracmort et al. 2010), and the Bi-Partisan Policy Center (Long et al. 2011) in the USA; and, in Germany, the Ministry for Education and Research (Rickels et al. 2011). The Intergovernmental Panel on Climate Change (IPCC) has held an expert meeting to discuss geoengineering (IPCC 2012) and will include a review of geoengineering technologies in its Fifth Assessment Report.

Research in many disciplines, including climate science, engineering, 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". It recommended "The development and implementation of governance frameworks to guide both the research and development … and possible deployment" (Shepherd et al. 2009: 57).

Following publication of the Royal Society report, the UK House of Commons Select Committee on Science and Technology initiated an inquiry into 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 2010:75).

The Oxford Principles are not the only set of principles proposed in relation to geoengineering but they have been the most influential. The report of the Select Committee on Science and Technology found 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*" (House of Commons 2010: 35). The UK Government (2010) subsequently endorsed the Select Committee report, including the Oxford Principles. The Oxford Principles were presented to the international scientific community at the Asilomar Conference on Climate Intervention Technologies and were "generally endorsed" by the conference (The Economist 2010:75). 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: 8).

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 about how they are to be implemented. The purpose of this article is therefore to: 1) explain the motivations for and intended functions of the Oxford Principles, 2) elaborate on the societal values they were intended to capture, and 3) propose a structure for the development of specific guidelines or protocols for different kinds of technology to ensure that the Principles are appropriately implemented. We begin by reviewing the reasons why interest in geoengineering is increasing and the concerns it raises.

2 Why geoengineering?

Concern over the slow process of international negotiations to reduce emissions of greenhouse gases (GHGs) is the primary reason for the interest in geoengineering. Since Paul Crutzen's (2006) article in *Climatic Change* brought it into the mainstream, leading scientists have begun to talk publicly about the potential for geoenginering to be a "Plan B" (Kunzig and Broecker 2008; Walker and King 2008). There are several reasons for this: 1) The world is nowhere near meeting mitigation targets, but is currently following the highest emissions trajectory envisaged by the IPCC. 2) Those mitigation targets might themselves be optimistic, since the IPCC scenarios assumed that the amounts of energy, and of carbon needed to create each new unit of global wealth (GDP), would fall, rather than rise as it has done. 3) Mitigation activities may exacerbate warming in the near term because reducing CO_2 emissions will also reduce emissions of sulphate aerosols that reflect sunlight back into space, partially offsetting the warming effects of CO_2. 4) Some geoengineering measures seemingly have potential to shave the peak global warming and "buy time" in which to reduce CO_2 emissions (Wigley 2006). 5) Some suggest that geoengineering would be a cheaper alternative to mitigation (Barrett 2008). Finally, 6) there is commercial potential in the development, construction and operation of geoengineering technologies.

Although the reasons for pursuing geoengineering are varied, and all are problematic, there seem to be 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 responses. However, at present, all geoengineering technologies are speculative and extensive research into their technical, environmental, socio-political, ethical and economic characteristics is necessary before their use could be sensibly contemplated.

3 What should we worry about?

Scientists and climate activists are divided over the wisdom and practicality of geoengineering. For many people, there is an "underlying feeling of abhorrence" (Keith 2000: 277) associated with the prospect. Experiments such as the Indo-German LohaFex ocean fertilization trial and the SPICE project's proposed, but eventually cancelled, field trial of a sulphate aerosol delivery mechanism have already caused controversy (see respectively Gross 2009, and 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 (although for a notable exception, see ETC Group (2010)). Nor is there any sign of governments acting to stop geoengineering research, even if their interest is restricted to a "watching brief" (Joan Ruddock MP, Minister of State, Department of Energy and Climate Change, quoted in House of Commons 2009: ev 27).

Concerns are as varied as the technologies under consideration. For some, geoengineering is symptomatic of humanity's hubris and a signal that the human attitude towards the natural world is seriously wrong (Fleming 2010; Gardiner 2010). Others worry about its effects on social justice and legitimacy. Many fear the "moral hazard" (Baker 1996) that conducting research into geoengineering might encourage a relaxed attitude towards emissions reductions. Another worry is the possibility of either social or technical lock-in. For example, stratospheric sulphate aerosol injection without complementary mitigation presents what has been called the *termination effect* (Shepherd et al. 2009: 35). If the programme is discontinued for any reason, the result would be a rapid rise in global temperature that could be harder to manage than any temperature increase that would have occurred without intervention. There is no comparable technical lock-in with carbon dioxide removal technology—for example, carbon dioxide removal machines could be simply switched off—but capturing CO_2 from ambient air and storing it is likely to require highly capital-intensive physical infrastructure. The sunk costs involved could create a vested interest in keeping the facilities operational, creating a social lock-in.

While some technologies pose problems because of their expected high costs, others raise challenges because they might be cheap. Stratospheric sulphate aerosol injection is sometimes claimed to be cheaper than emissions reduction (Barrett 2008; Bickel and Lane 2009). Although cost estimates vary widely according to input assumptions and are thus contested (see for example, Pielke Jr 2010; Robock 2009; Rickels et al. 2011), predictions of low costs might encourage some to promote sulphate aerosol injection research over other measures. Moreover, if those predictions are correct, it could be possible for a single country or even a individual frustrated with the pace of climate negotiations to deploy sulphate aerosol injection unilaterally (Victor 2008). Other areas of contention include the extent to which the private sector should be permitted to engage in geoengineering activities and how to redress any harmful side-effects of testing or using the technologies.

These considerations suggest that the issue of social control over the technologies is vital in deciding whether to proceed with geoengineering research. Public resistance to new technology is seldom only 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 lost, public trust cannot readily be restored (Slovic 1993). To allay such concerns, there is a pressing need for a governance regime for geoengineering research and for any eventual deployment. The Oxford Principles highlight the fact that the question of social control over geoengineering technologies will be key, and signal core societal values that must be respected if geoengineering research and any possible deployment is to be legitimate. They also emphasize 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.

4 The Oxford Principles

The original text of the Oxford Principles is 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).

5 The intentions behind the Oxford Principles

The Principles are proposed as a draft framework to guide the collaborative development 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 to deploy or not 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 geogengineering governance regime should look like. There are at least two aspects to this question. First, what values 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 stimulate a discussion between policy-makers, scientists, civil society groups and citizens about the overarching societal values that should be embodied in a geoengineering governance system. In this discussion, some Principles might be reformulated, or replaced, and others added.

Proposing a set of governance principles naturally invites questions about their implementation. The Oxford Principles were intended to provide a flexible 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.

6 The function of the Oxford Principles

It is immediately obvious that the Oxford 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 in the Oxford Principles was criticized in a recent Nature editorial (Nature 2012). However, in this instance, abstraction is not a disadvantage. Given the heterogeneity of proposed geoengineering methods and their varying degrees of development, it is undesirable, if not impossible, for the Oxford Principles to be anything but high-level. A "one-size fits all" approach is certainly not appropriate (Rayner et al. 2009: Preamble). The authors 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 research project. As such, the Principles suggest how 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 are many contextual factors in determining whether a physician has acted negligently, but the fact that not all can be specified in advance does not mean that there is no need for a principle against clinical negligence. Indeed, most people would be rather concerned if there were not.

The medical world provides us with a partial analogy in the Belmont Principles, which form part of the governance of medical research in the United States. Three principles, *respect for persons*, *beneficence* and *justice*, were proposed to protect human subjects in medical research (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). They are high-level, rather than directly action-guiding—some describe them as embodying an *ethos* (Gabriele 2003). Commentators recognize 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: 13) and that they must be reinterpreted 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 that sanction research proposals. As each of the key values behind the Belmont Principles required elaboration, it is appropriate here to elaborate on the values embodied in the Oxford Principles.

7 The 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.

7.1 Principle 1: geoengineering to be regulated as a public good

Principle 1 acknowledges that all of humanity has a common interest in the good of a 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, 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.

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. Persuing research may create powerful vested interests, for example in intellectual property. This issue was highlighted in a second memorandum from the Oxford Principles authors (Kruger et al. 2010), submitted after some Select Committee witnesses raised questions about Principle 1. Without precluding a role for the private sector, or the granting of patents, it is the case that the distribution of intellectual property rights can result in, or exacerbate existing, injustices. There should therefore be a presumption against exclusive control of geoengineering technology by private individuals or corporations. This does not mean that there can be no intellectual property in geoengineering, but 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.

7.2 Principle 2: public participation in geoengineering decision-making

Principle 2’s requirement of public participation suggests a primary concern for 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? 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.

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, as more people stand to be affected in the relevant sense. The location of infrastructure is an important concern in many 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 seems inappropriate 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 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 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 expect only 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.

7.3 Principle 3: disclosure of geoengineering research and open publication of results

Principle 3 requires the prompt and complete disclosure of research plans and open publication of results in order to facilitate better understanding of the risks and to allow the public to assure itself as to the integrity of the process. The requirement for complete disclosure and open publication of results is an appeal to the procedural value of transparency. 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 laboratory and field testing. Mindful of some well-publicized 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* should 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: 14). However, in the face of controversy, NSABB eventually decided that publication of revised papers (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). Much more could 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. The burden of proof should fall on the advocates of any restriction.

7.4 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. 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.

The need for independence is clear: to ensure that the assessment is impartial and unbiased. But 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, it possible only to highlight the questions that are likely to arise, rather than give specific answers at this stage.

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 minimize any effects 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 organizations and NASA. Studies of the organisational culture and structures of "high reliability organizations" (e.g. LaPorte 1996: 63–65) could provide guidance for developing an appropriate culture in research institutions and for setting up independent review bodies.

7.5 Principle 5: governance before deployment

Principle 5 is intended to address the transition from geoengineering research to deployment. The boundary is fuzzy: an experiment that could determine the efficacy of some techniques might 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 such a 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. Whether governance of a geoengineering technique rests with new or established institutions, such institutions must be accountable. Accountability includes the procedural norms embodied in Principles 2, 3, and 4. It also should include a right to appeal decisions and a mechanism for compensating those who are made worse off by any decision to deploy geoengineering. 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. Justifications of deployment decisions will most likely appeal to the basic societal values expressed in the earlier four Principles and perhaps others.

8 Future directions

If the Oxford Principles are to be of any practical value, attention must be paid to how they are to be implemented. Any geoengineering governance system must face a difficult challenge: the *technology control dilemma* (Collingridge 1980). It is all but impossible in the early stages of a technology's development to know how it will turn out in its final form. Mature technologies rarely 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. However, this dilemma can be overcome. Various characteristics of technologies that contribute to inflexibility and irreversibility can be identified. These include high levels of capital intensity, hubristic claims about performance, and long lead times from conception to realization, to which the UK Royal Commission on Environmental Pollution (RCEP) recently added, in the context of nanoparticles, "uncontrolled release into the environment" (RCEP 2008: 8). Flexibility must therefore be built into the governance of geoengineering. An incremental, bottom-up process, guided by values and mindful of problems such as the control dilemma is most likely to deliver it.

It is therefore envisaged that the Principles will form part of a flexible architecture for geoengineering governance, which will eventually be realized 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 institutionalization 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 recognized 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.

9 Towards implementation: technology-specific research protocols

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 deployment. 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 a blending of these roles, such as the EU step-by-step approvals process for GMOs, which combines the provision of independent scientific advice by an expert body at the environmental assessment stage, with legal authorisation by the Commission and Member States. Where an experiment has the potential for transboundary impacts, 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.

10 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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