



Public perceptions of geoengineering research governance: An experimental deliberative approach



Rob Bellamy^{a,*}, Javier Lezaun^a, James Palmer^b

^a Institute for Science, Innovation and Society, University of Oxford, 64 Banbury Road, Oxford, OX2 6PN, UK

^b School of Geography and the Environment, University of Oxford, South Parks Road, Oxford, OX1 3QY, UK

ARTICLE INFO

Keywords:

Climate engineering
Controllability
Experimentation
Geoengineering
Governance
Public perceptions

ABSTRACT

Recent attempts to conduct experiments in climate ‘geoengineering’ have demonstrated the deeply controversial nature of this field of scientific research. Social scientists have begun to explore public perceptions of geoengineering, and have documented a significant degree of concern over the effective governance of research and experimentation in this area. Yet, public perception on what constitutes a legitimate geoengineering experiment and how it should be governed remains under-researched. In this article we report on a series of experimental deliberative workshops with members of the public designed to elicit and explicate diverse understandings of geoengineering experiments and their governance. In contrast to previous methods of invited public deliberation, which privilege egalitarian-consensual models of discourse and decision-making, we test a novel approach that places majoritarian, individualistic, and consensual forms of public deliberation on an equal footing. Our study suggests that the perceived controllability of experimental interventions is central to public views on their acceptability, but that controllability is itself a complex, multifaceted quality, drawing together a set of heterogeneous concerns about the purpose and repercussions of scientific work. The citizens who participated in our workshops employed four criteria to adjudicate the acceptability of geoengineering experiments: (1) the degree of *containment*; (2) the *uncertainty* surrounding experimental outcomes; (3) the *reversibility* of impacts; and (4) the scientific *purity* of the enterprise. We theorize that the public legitimacy of geoengineering experiments depends on variable, context-specific combinations of these criteria, and that technical determinations of the proper ‘scale’ or ‘location’ for geoengineering research will be poor predictors of the sorts of public concerns that will be triggered by further experimentation in this area.

1. Introduction

The possibility of carrying out deliberate large-scale interventions in the Earth’s climate system has emerged as a controversial addition to the arsenal of options to moderate anthropogenic climate change. These ‘geoengineering’ or ‘climate engineering’ proposals comprise variants that seek to remove carbon dioxide from the atmosphere (carbon geoengineering), or to reflect a fraction of sunlight away from the Earth (solar geoengineering). Scientists and engineers have begun to design and conduct experiments to test the technical viability of some of these ideas. Some of these trials rely on familiar technologies (e.g. the production and burial of pyrolyzed biomass, or ‘biochar’), unfold in virtual environments (e.g. through computational modelling), or involve ostensibly non-invasive scales of research (e.g. they unfold within a laboratory). The few experiments that have tested new or unfamiliar technologies in the open have, however, attracted a significant degree of public interest and media scrutiny. Notable cases include the

proposed testbed for a stratospheric aerosol delivery mechanism included in the UK Stratospheric Particle Injection for Climate Engineering (SPICE) project (Stilgoe, 2015), and the ocean iron fertilisation release carried out by the Haida Salmon Restoration Corporation in the North Pacific (Tollefson, 2012).

The obvious public interest in the design and conduct of geoengineering experiments has led to calls for broader civil society consultation on the definition of acceptable and unacceptable geoengineering research. The 2010 Asilomar International Conference on Climate Intervention Technologies, for instance, concluded with a recommendation for “public participation and consultation in research planning and oversight.” Similarly, the recent reports issued by the U.S. National Academies of Science on the research that ought to underpin different forms of “climate intervention” argued that “open conversations about the governance of such research, beyond the more general research governance requirements, could encourage civil society engagement in the process of deciding the appropriateness of any research

* Corresponding author.

E-mail address: rob.bellamy@insis.ox.ac.uk (R. Bellamy).

efforts undertaken” (National Research Council 2015: 153; see also Rayner et al., 2013; Burns and Flegel, 2015). These calls join broader arguments for “upstream” citizen engagement in the formulation and assessment of scientific research agendas (Wilsdon and Willis 2004; Stilgoe et al., 2014), specifically in areas characterized by incertitude and ambiguity (Stirling, 2007), and where social commitments are still indeterminate or contingent (Wynne, 1992). The current emphasis on “responsible” forms of scientific research and innovation equally emphasize the need for governance processes that are anticipatory of impacts, reflexive of assumptions, inclusive with respect of the multiple possible framings of the matter at hand, and responsive to changing societal values and concerns (Stilgoe et al., 2013).

Social scientific research has begun to explore public perceptions of geoengineering, and has identified growing interest in the effective governance of scientific research and technical experimentation in this area. Deliberative workshops undertaken for the SPICE project testbed, for instance, suggested public support for greater transparency in research funding decisions, open publication of results, and new international governance and regulatory structures (Pidgion et al., 2013). Focus groups on solar geoengineering have stressed the need for public confidence on at least five fronts: in climate science as a reliable guide to policy; in the ability of research to predict side effects; in the ability of research to demonstrate efficacy; in effective research governance; and in the capacity of democratic institutions to accommodate solar geoengineering technologies (Macnaghten and Szerszynski, 2013; Merk et al., 2015). Government-sponsored public engagement exercises on geoengineering proposals have elicited concerns about the controllability, reversibility, and cost-efficiency of different geoengineering options (NERC, 2010). Public appraisals of geoengineering proposals against other options for tackling climate change have led to three criteria for good governance: greater reflexivity in the articulation of geoengineered futures, the prioritization of broadly “robust” options and decisions over narrowly “optimal” ones, and the need to satisfactorily engage concerned publics before declaring geoengineering a legitimate object of scientific governance (Bellamy et al., 2016; Bellamy, 2016).

Despite these advances in the formulation of general principles for the effective governance of geoengineering, however, there is still little evidence on public perceptions of what might constitute a legitimate geoengineering experiment and how it should be governed (Parkhill and Pidgion, 2011; Pidgion et al., 2013). In this article we report the findings of a series of experimental deliberative workshops designed to elicit and explicate diverse understandings of geoengineering experimentation, and of the adequacy of different models of research governance. In contrast to previous methods of public deliberation, which have largely privileged egalitarian forms of discourse and consensual decision-making, we develop here a novel approach that places majoritarian, individualistic, and consensual models of public deliberation on an equal footing. Our study suggests that the controllability of experimental interventions is central to public perceptions of their acceptability, but that controllability is itself a multidimensional construct, encompassing concerns about physical containment, uncertainty about experimental outcomes, reversibility of impacts and conformity with ideals of ‘pure’ science. The ability of citizens to mix these four criteria in different combinations points to the limits of governance regimes that rely on a single parameter to define controllability, such as those premised on a purely linear determination of scale (large/small), or those that assume the overriding importance of physical location (indoors/outdoors). In light of these findings, we explore the multifaceted, non-linear nature of the “control dilemma” that characterizes the governance of emerging science and technology (Collingridge, 1982). We conclude by elaborating on the potential and limitations of our own experimental approach to public deliberation, and suggest some avenues for further refining our method.

2. Theory and method

To better explore public understandings of geoengineering research and views on the appropriate mechanisms for its governance, we devised three ideal-typical workshop formats: ‘majoritarian,’ ‘consensual,’ and ‘individualistic’. As the names suggest, each workshop followed a different set of rules for argumentation and decision-making. We complemented these rules with a different style of facilitation and room layout for each of the groups, in an effort to encourage group dynamics aligned with the respective constraints placed on the process of deliberation. The three workshops were held on the same day in Norwich, Norfolk (UK), and were facilitated by the three authors.

In the majoritarian workshop, participants were compelled to reach a decision by majority vote, allowing, in the event of dissent, a single minority report. We provided the group with a theatre-style room layout, and enforced each participant’s right to have the floor when speaking. The facilitator did not step in to facilitate the resolution of differences of opinion, nor did he assist in the formulation of an agreed group position. In the consensual workshop, participants were compelled to reach a unitary group position. Failing that, they were asked to represent in their conclusion every viewpoint expressed within the group. The facilitator ensured that every participant had a chance, and indeed an obligation, to speak, and guided the exchanges towards the articulation of a shared group view. The workshop took place in a room with a circular open space layout. Finally, in the individualistic workshop, which took place in a room with a boardroom-style layout, the facilitator encouraged the maximum articulation of individual viewpoints and the confrontation of differing opinions. He allowed individuals to try to persuade the rest of the group towards a consensus or majoritarian decision, but did not facilitate the emergence of a unitary position.

In designing each of these workshop formats, we took inspiration from the cultural theory of risk developed by Mary Douglas and Aaron Wildavsky (1982). The theory posits three ideal-typical worldviews, or ‘cultures’, on the basis of a preference for a particular kind of social organisation: hierarchical, egalitarian and individualistic. It argues that these biases will structure risk perception, a hypothesis that has been explored, through survey research, in relation to nuclear power (Peters and Slovic, 1996), genetically modified organisms (Finucane, 2002), nanotechnology (Kahan et al., 2009), and geoengineering (Bellamy and Hulme, 2011; Kahan et al., 2015).

In our exercise we attempted to translate the categories of cultural theory into deliberative formats. We modelled the majoritarian workshop after the hierarchical cultural type, the consensual workshop after the egalitarian type, and the individualistic workshop after the individualistic type. In developing specific modes of facilitation and decision-making for each of the workshops, we drew on work in social psychology that explores the configuration of “political atmospheres” or “social climates” in laboratory-like settings (e.g. Lewin et al., 1939). This body of work contends that different forms of political organisation can materialize in small groups under experimental conditions with the help of adequate facilitation techniques and socio-technical arrangements (cf. Lezaun and Calvillo, 2014).

We recruited participants to each of these workshops based on their affinity with hierarchism, egalitarianism or individualism, as measured by a psychometric survey modified from Dake (1991). This survey consisted of statements designed to measure degrees of affinity with each of the three cultures alongside a four-point Likert scale ranging from ‘strongly agree’ to ‘strongly disagree’ (see Bellamy and Hulme, 2011). Through this survey we also gathered information on sex, age, and National Statistics Socio-Economic Classifications (NS-SEC), the standard governmental measure of socioeconomic status in the UK, in order to produce a study population that was broadly representative for the county of Norfolk, although this was of secondary importance to recruitment on the basis of cultural predisposition.

The recruitment survey was administered online through Norfolk

Table 1
Participant profiles from the majoritarian (A1–6), consensual (B1–7) and individualistic (C1–8) workshops.

Code	Culture ^a	Sex	Age	NS–SEC
A1	A	F	45 – 64	4 – 9
A2	A	F	45 – 64	4 – 9
A3	A	F	45 – 64	1 – 3
A4	A B C	M	45 – 64	1 – 3
A5	–	M	45 – 64	4 – 9
A6	–	M	45 – 64	1 – 3
B1	B	M	24 – 44	1 – 3
B2	B	F	45 – 64	1 – 3
B3	B	F	45 – 64	1 – 3
B4	B	M	45 – 64	1 – 3
B5	B	F	65+	4 – 9
B6	B A C	F	65+	4 – 9
B7	B	M	65+	4 – 9
C1	C	F	18 – 24	4 – 9
C2	C	F	45 – 64	4 – 9
C3	C	F	45 – 64	1 – 3
C4	C B	M	45 – 64	4 – 9
C5	C	F	65+	4 – 9
C6	C	M	65+	1 – 3
C7	C	M	65+	1 – 3
C8	C	M	65+	1 – 3

^a ‘Culture’ refers here to an affinity for ideal-typical ways of organising social relations, as defined by Douglas and Wildavsky (1982). Acronyms: majoritarian (A), consensual (B), individualistic (C). Where participants showed an affinity for more than one ideal-typical form of organisation, predispositions were ordered by strength of association. Where participants showed no affinity for any ideal-typical form of organisation, none are shown. Across the 163 survey respondents, Cronbach’s alpha coefficients showed reliable internal consistencies for the consensual ($\alpha = 0.67$) and individualistic ($\alpha = 0.71$) scales, but not for the majoritarian ($\alpha = 0.27$) scale.

County Council’s ‘Your Voice’ citizen membership scheme as a ‘topic blind’ workshop on ‘global environmental issues’. Of 163 respondents, twenty-one participants were recruited. Of those, six were allocated to the majoritarian workshop; seven were allocated to the consensual workshop, and eight were allocated to the individualistic workshop (see Table 1). Selected respondents received an honorarium for their participation in the workshops.

Our goal with this diversification of group formats was two-fold. First, we wanted to avoid the reliance of public engagement methods on a single model of deliberative exchange, namely the egalitarian-consensual model derived from theories of deliberative democracy. Decisions on geoengineering research (or on any other public issue, for that matter) are unlikely to be produced only within egalitarian-consensual contexts. By expanding the range of group formats, and specifically by considering situations in which participants are encouraged to reach decisions in agonistic contexts, we hoped to generate a richer set of argumentative strategies and discursive frames relating to geoengineering (Bellamy and Lezaun, 2017; Chilvers and Kearnes, 2016). Second, the use of three different workshop designs allowed us to explore whether each form of deliberation and decision-making led to markedly different positions on the acceptability and adequate governance of geoengineering research. This expectation would be in line with existing literature on the institutional and cultural determinants of risk perception and technological choice (e.g. Rayner and Cantor, 1987), but here we tested the hypothesis in deliberative situations, rather than through the use of opinion surveys as has traditionally been the case.

In pursuing this experimental deliberative approach to public perceptions of geoengineering research governance, our method ran into some unexpected challenges. In particular, the uneven distribution of technical expertise within each of the groups quickly manifested itself as a relevant variable in the evolution of the group’s position, as participants who displayed a greater level of familiarity with the technical questions were able to influence the course of the group’s deliberation.

The distribution of expertise within each of the groups thus became a factor that neither the formal decision-making rules nor the facilitation style could fully keep in check. We reflect on the limitations of our approach, and on ways to refine it further, in the final discussion.

The exercise comprised three distinct phases. In the first phase, which lasted 30 min, participants from all three workshops gathered in plenary and were given brief introductory presentations on: (1) the causes and risks of anthropogenic climate change; (2) generic options for tackling climate change (mitigation, adaptation and geoengineering); and (3) four specific geoengineering proposals selected for their policy relevance and functional diversity. These four geoengineering proposals were: (1) stratospheric aerosol injection; (2) ocean iron fertilisation; (3) marine cloud brightening; and (4) the industrial capture of CO₂ from ambient air to be stored underground (air capture and storage). Our introduction situated geoengineering within the broader context of climate change in order to avoid the narrower framings that had beset early public engagements with the field (Bellamy et al., 2012; Bellamy and Lezaun 2017). The brevity of our introduction was partly intended to limit its ability to pre-form views and opinions on the matters under discussion.

In the second phase, participants convened in their allocated workshops and were invited to discuss their initial reactions to the four geoengineering proposals under consideration. Each workshop gathered for 90 min, and followed the specific set of discursive and decision-making rules described above. Participants from all three workshops then reconvened in plenary to receive a further 15-min presentation on four ideal-typical models for the governance of geoengineering research. The four models were: (1) self-regulation, where research is overseen by scientists within the parameters of traditional peer-review (cf. Parson and Keith, 2013); (2) the establishment of a new independent body with the power to review and approve proposals for new research on geoengineering (cf. Rayner et al., 2013); (3) the negotiation of an international agreement harmonizing the conduct of geoengineering research across countries (cf. Bodle et al., 2014); and (4) the enactment of an international moratorium banning any further research (cf. Hulme, 2014). Each of these governance models was defined with sufficient flexibility to encourage participants to elaborate its parameters as appropriate.

In the third phase, participants reassembled in their respective groups to discuss the four governance options in a further 90-min session. Participants were encouraged to discuss one geoengineering proposal at a time, and were told that for each proposal they could adopt one of the governance models, combine elements of several of them, or develop an entirely new alternative. Facilitators emphasized that the discussion pertained to *research* on geoengineering, and not to the ultimate *deployment* of geoengineering technologies. In addition, facilitators sought to elicit views on how different governance models might apply to different ‘scales’ of experimentation discussed in the geoengineering literature: computer simulations, laboratory experiments, and small-, medium- and large-scale outdoor experiments. As we will see, the distinction between research and deployment was not easily maintained in the course of the discussions, nor did it map neatly onto the various ‘scales’ of experimentation. Indeed, the proper characterization of an experiment – how best to define its ‘location’ or ‘scale’ – became a crucial and contested element in the deliberations over alternative governance regimes.

In the course of the discussion, facilitators did not introduce the question of the potential trade-offs between the risks posed by geoengineering research and those posed by pre-existing anthropogenic climate change. At the same time, they did not prevent participants from exploring the question if they so wanted. Although other public engagement exercises have actively investigated this issue, largely by presenting geoengineering as a possible response in the event of a ‘climate emergency’ (e.g. NERC, 2010), we believed that framing the deliberations in this manner would have introduced a false dilemma, as geoengineering is only one among several possible courses of action to

reduce the threat posed by climate change. We have researched public perceptions of geoengineering risks and benefits in comparison to those of mitigation and adaptation elsewhere (Bellamy et al., 2016).

All workshops were audio recorded, fully transcribed, and subject to qualitative coding analysis by two of the authors for inter-coder reliability using the framework developed by Krueger (1994). This coding sought to identify recurrent themes and discursive frames used by participants in their reasoning about geoengineering research and its governance. It served to map the key structures of argumentation that emerged in the workshops, rather than to produce a quantitative or statistical representation of the positions expressed in the course of the discussions.

3. Findings

3.1. Majoritarian workshop

The discussion in the majoritarian workshop focussed on the limitations of self-governance by scientists as a method to regulate geoengineering research. The most assertive member of the group framed the discussion from the outset by arguing that:

“You’ve got [to have] somebody coming in from the outside with a fresh pair of eyes to see whether what [scientists] are doing is actually appropriate” (A2).

Concern that scientists might ‘create Frankenstein’s monster’ led participants to recall a range of ostensibly analogous regulatory debacles in the UK and beyond that showed the limitations of self-governance by experts or professionals. Examples mentioned in the discussion extended well beyond science and technology. They included, for instance, racism amongst police officers requiring the establishment of the Independent Police Complaints Commission, illegal practices amongst the press leading to the Leveson Inquiry, and patient harm caused by novel pharmaceuticals resulting in government agencies imposing tougher drug approval procedures. All of these were cited as demonstrations of the need for external scrutiny and oversight of professional communities. The so-called ‘Climategate’ affair was also invoked to support this idea, with the argument that “whether it’s true or not I do think that there needs to be somebody independent overseeing that” (A2).

When put to the vote, a clear majority position emerged on the most appropriate model for the governance of geoengineering research. This view did not think it necessary to differentiate between different geoengineering methods, but emphasized the need to discriminate between different levels or phases of research. As A2 put it:

“I don’t think the rules should be any different irrespective of what the research is... Should we not just have rules for research: if you want to do research this is what you need to do? I think you’re blurring the boundaries then [if you treat different geoengineering proposals differently], because scientists will be going, ‘Ah yes, but mine doesn’t fit into that, it fits into this. And therefore I should be allowed to do this; whereas you’re doing this and you shouldn’t be allowed to do that’”.

Although several participants noted the difficulty in neatly separating different levels or phases of research, the key threshold was identified at the point when research is conducted outside the laboratory. This was the moment when researchers were thought to be “stepping over the line” (A5).

A majority of participants expressed a preference for governing indoors geoengineering research, including computer modelling, through a new independent body. Because all the forms of experimentation under discussion were seen to carry international implications, be those collective action challenges in the case of air capture and storage, or transboundary risks and impacts in the case of the three other proposals, any outdoors research was thought to require some sort of prior

international agreement, although the details of such an agreement were not specified (A1, A2, A5, A6). A majority of participants were careful, however, to explain that this view did not imply an endorsement of a research moratorium *per se*: “I’m not about risk avoidance, I’m about risk management” (A2).

A minority of members of the majoritarian group appeared less concerned about issues of external review and at the same time offered more nuanced views on individual geoengineering methods. Warning against the risk of stifling scientific creativity, these participants also argued that the distinction between indoors and outdoors research was not always the most relevant consideration. In some cases, for instance, research could be conducted outdoors at such small scales as to merit no additional independent oversight:

“A machine sucking out a few kilograms of CO₂ out of the atmosphere [is] not going to keep me awake at night really”... “I’m pretty relaxed about [ocean iron fertilisation] in the light of the chemicals that get pumped into the sea every day”... “I’d be pretty relaxed about sticking some salt into the air really, quite frankly”... “Sulphate particles: I feel less relaxed about this one than any of the others. Perhaps because it’s sulphate it sounds like a chemical sounding word. If you think of it as volcanic ash it doesn’t sound quite as horrendous. But, as I keep reminding myself, we’re only talking about research”. (A4)

Accordingly, the minority report expressed a preference for governing all geoengineering research through self-regulatory measures up to a certain phase in the research and development process (A3, A4). In contrast to the majority position, however, this minority thought that the threshold for external, independent oversight should be defined differently for different geoengineering options. In the case of air capture and storage and marine cloud brightening, for example, self-regulation was thought appropriate for all levels of phases of research, but an international agreement was deemed necessary prior to deployment. For ocean iron fertilisation, self-regulation was seen as appropriate for research in ‘controlled zones,’ but an international agreement was thought necessary for research in ‘open zones’. In the case of stratospheric aerosol injection, the governance of ‘indoors’ research could be left to the scientists themselves, but any ‘outdoor’ experiment was thought to require an international agreement, and a moratorium should be placed on any outdoor experiments exceeding a ‘medium’ scale.

3.2. Consensual workshop

Most of the discussion in the consensual workshop centred on the role of an independent review mechanism and its relation to the benefits and shortcomings of allowing scientists to regulate themselves. The discussion was initially framed by B4, a retired government scientist, who placed geoengineering research firmly within the framework of other scientific activities that are routinely funded, and thus overseen by, government or research funding organisations. Given its lack of commercial application, he argued, geoengineering research was likely to be funded by public institutions, and these would naturally introduce a form of independent review in the process of selecting and approving research projects:

“If you’ve got to apply for money you immediately subject yourself to independent review. That’s why I say that [self-regulation] is actually a non-starter here”. (B4)

As a contrast to this world of regulated science, B4 introduced the figure of the ‘maverick’ to describe individuals “who decide that nothing’s going to control them; that they want to do something independently.” In the opinion of B4, the maverick was someone who challenged “the wisdom of the community,” was able to operate without external support, and was thus prone to introduce unacceptable risks.

The question of how independent review and self-governance by scientists might relate to one another was introduced multiple times by the facilitator, but failed to gain traction as a topic of discussion. The issue was addressed, however, later on, when the specific question of who should be involved in the independent review of geoengineering research proposals was posed. B4 introduced here a distinction between ‘pure’ (or ‘blue skies’) and ‘applied’ research, in the context of a discussion about whether, and when, a bioethicist should be involved in the evaluation of stratospheric aerosol injection:

“You don’t need to ask bioethicists as to whether the shape of a sulphate particle is going to reflect light, it’s not relevant. But if I was then to say: ‘well, I have developed this particle which is the perfect shape for reflecting light, I now want to inject it into the atmosphere.’ The impact of that and the scope of that is so huge that the breadth of reviewers you have to go to must also be equally huge, because then you’re talking about climatologists, you’re talking about chemists as well, physicists as well, but you’re also talking about people who understand the stratosphere, you’re talking about almost everybody.” (B4)

Several other members of the group found the distinction between ‘pure’ and ‘applied’ research useful, and they returned to it repeatedly in the course of the workshop to make sense of other aspects of geoengineering research governance. As the above quote indicates, another critical distinction was provided by the location of experimentation. For many in the group the conduct of research outside the laboratory represented the most significant threshold as far as the appropriate form of governance was concerned. Views in favour of an international agreement, for instance, multiplied when the possibility of operating outside contained scientific facilities was discussed. The only exception to this rule was air capture and storage, which was thought to require national-level regulation at most, regardless of the location or scale of the experiment. In the case of stratospheric aerosol injection, several participants noted that for a release to constitute a meaningful experiment it would have to involve large quantities of chemicals:

“Some of those things like the last one, sulphur particles, how would you...? You’d have to do it on a large scale to be able to have an effect because as soon as you put those particles up they’d just disperse into such thin concentrations that there’d be no way of monitoring their effectiveness. So that would have to have a wider agreement I guess, if you were actually going to be serious about putting it into the large-scale research. So the more ambitious the project and the harder it is to confine, the more general consensus you have to have”. (B7)

In other words, some participants perceived a proportional relation between the scientific value of an experiment and the degree of consensus it would require, at least in the case of the release of sulphate particles into the stratosphere. Furthermore, the above quote also suggests that the distinction between ‘research’ and ‘deployment’ was not always central to the group’s understanding of the governance challenges at hand. When the discussion shifted to the need for international agreements, specifically in relation to stratospheric aerosol injection and ocean fertilisation, it was often difficult for participants to parse whether such an agreement would cover only research or should also be extended to deployment. The view expressed by a majority of participants seemed to be that, given the implicit transboundary impacts associated with these options, any intervention in the open environment ought to be preceded by a clear set of international rules, regardless of whether this intervention was categorized as ‘research’ or ‘deployment.’ Questions about who could or should be in a position to lay down such rules led to a discussion about the role of the UN and associated bodies. Examples of comparable legal instruments were offered, for instance international agreements banning intervention in the Arctic, whaling, or the exploitation of the moon. Yet it was generally felt that a similar initiative for geoengineering was unlikely to succeed

given the current state of international institutions and the degree of geopolitical rivalry among major powers.

For all participants, however, support for an international agreement did not imply support for a ban or a moratorium on geoengineering research. In fact, asked by the facilitator if they could think of any area of scientific inquiry, apart from geoengineering, for which an immediate ban on research would be justified, participants were unable to identify any. It was generally felt that a robust independent review mechanism involving relevant scientific experts (including, in some cases, bioethicists) would be sufficient to exclude any form of research deemed socially or ethically unacceptable. Bans or moratoria on research were thought to be incompatible with scientific progress – itself a pre-condition for the effective governance of new technologies:

“I don’t think you could ever say you could make bans; you can make judgments. Otherwise you don’t make progress; you wouldn’t have the inoculations; you wouldn’t have the antibiotics; you wouldn’t have anything, would you? So banning things, controlling things, it’s different.” (B5)

3.3. Individualistic workshop

Many participants in the individualistic workshop initially sought to impose a straightforward, binary approach to the governance of geoengineering research. This binary approach differentiated between solar proposals (stratospheric aerosol injection and marine cloud brightening), which were viewed as more difficult to control and therefore requiring more stringent regulation, and carbon proposals (ocean iron fertilisation and air capture and storage), which were seen as less problematic and therefore more amenable to self-regulation by researchers. A minority of participants, however, strongly advocated a more nuanced view, emphasising questions of uncertainty and irreversibility across the four geoengineering options under discussion. C7, for instance, was persistent and often persuasive in asking others in the group to take a more sensitive approach to the degree of ignorance about the potential impacts of ocean iron fertilisation, and to be more critical of the reliability of any knowledge derived from small-scale experiments:

“I think the marine environment is just so fragile that anything other than the marine environment isn’t going to give you the information that you need. I think that’s the problem”. (C7)

Indeed, in the course of the discussion some participants came to articulate sophisticated ideas about uncertainty. C6, for instance, remarked on several occasions in relation to stratospheric aerosol injection that there was a ‘chicken and egg’ conundrum at play in the tension between reducing uncertainty through medium- or large-scale testing, on the one hand, and minimising the risk of potentially unknown impacts, on the other. For C5, this conundrum plagued any effort to scientifically establish the efficacy of marine cloud brightening via small-scale experiments:

“How the blazes do you know if you’re picking up cloud brightening in a small area [that it] is actually reducing the sun’s effect on the earth? Wouldn’t you have to do it on a global basis right from the word go?”

When the facilitator probed the possibility of ‘rogue’ experiments with ocean iron fertilisation, this provoked further introspection from some participants about the possibility of a ‘slippery slope’ between research and deployment, as in the following remark:

“If we’re not careful the next thing is they’ll have a medium [experiment]; or they might skip that and go straight into a big experiment. Especially with the ship one [ocean iron fertilisation] there might be one setting sail from Felixstowe this afternoon.” (C6)

More generally, participants invoked multiple analogies to think

through the potential implications of allowing researchers to govern their own work without external review: “It’s a bit like the press thing: could they be trusted to keep within their remit, I suppose” (C3). Many participants asserted that different governance mechanisms should be used to govern ‘pure’ and ‘applied’ research. As participant C6 put it: “You must let people do computer modelling and laboratory experiments”. Others similarly expressed concerns about stifling potentially valuable scientific progress through unnecessary regulation of ‘purer’ forms of research: “If you take pure research, I don’t believe in too much regulation, [because] I think it inhibits what you’re doing” (C8). Despite their concerns about the governance challenges involved, participants were in agreement that research into geoengineering should not be outlawed altogether.

In light of concerns about a ‘slippery slope’ between research and deployment, the majority of participants were unwilling to endorse medium- and large-scale geoengineering experiments before an international agreement setting out clear guidelines for the conduct of such research could be put in place. Only a minority of participants rejected this idea, preferring instead an independent review panel, on the ground that any international agreement would struggle to effectively regulate the wide diversity of geoengineering experiments being envisaged:

“Personally I would probably go more for the independent review body because every case is different and you can’t legislate for every single thing that might happen. That’s the trouble. You are going to have to have pretty elastic boundaries if you’re going to have an agreement.” (C2)

Regardless of participants’ views on the feasibility of designing an effective international framework, all participants agreed that this approach should apply to every one of the four geoengineering proposals discussed with the exception of air capture and storage, which – ostensibly due to its similarity to carbon capture and storage (CCS) technology – was deemed to carry less uncertainty and fewer risks and thus not require an international governance regime.

Whilst computer-based, indoor, and small-scale forms of outdoor experimental research were viewed as sufficiently benign for participants to place their trust in scientific self-regulation, many participants nonetheless argued for greater transparency in the conduct of research ‘at all levels’. For instance, all participants expressed surprise, and in some cases irritation, when they learned that technologies such as ocean fertilisation had already been tested, and most felt it was unacceptable that they hadn’t at least heard about these activities before. For some, their lack of awareness of recent geoengineering experiments fuelled additional concerns about the real motives and objectives of this activity. This was a particularly prominent sentiment where potential commercial involvement in research ventures was mooted, both in terms of who would fund the research itself, and who would benefit from any subsequent development of specific technologies:

“When you’re talking about environmental studies and so on, if they’re sponsored by some kind of Christian or religious organisation you might say ‘well that’s jolly good’. But if it’s Tata Motors or Ferguson Tractors you know, I’m a bit worried about it.” (C8)

4. Discussion

In line with the purpose of our original design, the three workshops elicited a wide range of opinions on the governance of geoengineering research. In fact, one of the most striking aspects of the exercise was the ability of participants to articulate diverse and fairly complex positions on the acceptability of different forms of geoengineering and on the benefits and challenges of the proposed governance models. This is particularly remarkable given the limited duration of the workshops and the cursory introduction to the topic participants had received before the discussions started. This experience is consistent with many

other consultation exercises on geoengineering (e.g. Corner et al., 2013; Macnaghten and Szerszynski, 2013; Bellamy et al., 2016; Wibeck et al., 2015), and suggests that lay citizens are more than capable of engaging with the issues under consideration in significant depth, regardless of their prior level of knowledge or awareness of geoengineering.

Although we did not intend to quantify levels of support for each of the four research governance models, it is apparent that most participants preferred intermediary regulatory measures that built on and expanded the mechanisms of peer- and independent-review that characterize the governance of scientific research in other areas. A desire not to stifle scientific progress, combined with latent scepticism about the capacity of institutions, particularly international ones, to produce effective regulations, restricted support for any form of global moratorium across all three groups (cf. Parker, 2014). At the same time, there was little support for self-regulation if this simply meant empowering scientists to conduct whatever research they wanted. Even those who were happy to endorse self-regulation assumed that scientific research is regularly and as a matter of course subjected to rigorous scrutiny, and that the same level of oversight should apply to geoengineering. The figure of the ‘maverick’ or ‘rogue’ experimenter served to highlight the default view of science as a well-governed domain constrained by institutional and communitarian rules.

As outlined in Fig. 1, each of the three workshops yielded a distinct set of preferences for the governance of geoengineering research. The majoritarian workshop formed two perspectives: a majority (four participants) expressed a preference for an independent review process in the case of indoor research, and an international agreement for any research unfolding outdoors. This approach should apply, in the view of this majority, across the four geoengineering proposals under consideration. The minority group, on the other hand, adopted a more nuanced and technology specific view (see Figure for details). The consensual workshop expressed a preference for self-regulation in the case of computational modelling, independent review for other indoor research, and an international agreement for outdoor research. These criteria applied to the four geoengineering proposals with the exception of air capture and storage, for which the workshop expressed a preference for governing outdoor research through national legislation. Finally, the individualistic workshop expressed a preference for self-regulation in the case of computational modelling, other indoor research, and small-scale outdoor research, and for an international agreement in the case of medium- and large-scale outdoor research. These criteria were applied to all of the geoengineering options under discussion except air capture and storage, where it was deemed that independent review, and not an international agreement, would be a more appropriate governance mechanism for medium- and large-scale outdoor research.

Since only one example of each ideal-typical workshop was staged in this study, it is difficult to judge with any degree of confidence the extent to which the outcome of the deliberations was linked to specific elements of workshop design. Some of the hypotheses that are commonly derived from the cultural theory of risk did not match the positions taken by the groups. For instance, cultural theory would suggest that a consensual group, inspired by the tenets of egalitarianism, would tend to express a preference for stricter regulatory approaches (e.g. an international moratorium) (Rayner, 1991). Yet, participants in our consensual workshop generally favoured ‘softer’ approaches to the governance of research, such as self-regulation by scientists, particularly in the case of indoors research. On the other hand, the individualistic workshop, modelled after the individualist bias described in cultural theory, would in principle be expected to favour softer regulatory approaches. In practice, however, this group yielded a clearer polarization of views depending on the nature of the research under consideration, with softer approaches advocated for indoors and small-scale outdoors research, and harder approaches preferred for medium- and large-scale outdoors research. Further investigations of the relationship between group format and deliberative outcome would

	Majoritarian workshop (majority)				Majoritarian workshop (minority)				Consensual workshop				Individualistic workshop			
	Self-governance	Independent review	International agreement	International moratorium	Self-governance	Independent review	International agreement	International moratorium	Self-governance	Independent review	International agreement	International moratorium	Self-governance	Independent review	International agreement	International moratorium
Stratospheric aerosol injection	I	O			I		O	>	M	I	O		<			>
Ocean iron fertilisation	I	O			C		U		M	I	O		<			>
Marine cloud brightening	I	O			R		D		M	I	O		<			>
Air capture and storage	I	O			R		D		M	I	N		<			>

Fig. 1. A comparison of majoritarian, consensual and individualistic workshop preferences for governing geoengineering research. Key: Indoor research (I); Outdoor research (O); Contained research (C); Uncontained research (U); Any research (R); Deployment (D); Computational modelling (M); National regulation for outdoor research (N); Any research below a medium scale (<); Any research equal to or above a medium scale (>).

require a refinement of the method used in this investigation, including possibly the introduction of control groups. Yet any experimentalization of cultural theory (or any other social theory for that matter) will have to contend with the emergent properties of groups created for research purposes. This point became salient in our investigation, for instance in the influence exerted by individuals with a professional scientific background (such as the retired government scientist in the consensual group) over the direction and substance of the discussions. We will return to the question of emergent group properties when we discuss opportunities for refining this experimental deliberative approach.

An especially relevant dimension in the dynamics of collective discourse was the choice of analogies used to make sense of the governance dilemmas attendant to geoengineering research. Participants in the three workshops often deployed forms of experiential expertise that went far beyond geoengineering. Some of these analogies concerned other controversial ‘emerging technologies’, but many, like the references to the external oversight of the press, for instance, or to existing international treaties for the protection of natural resources or nuclear weapons, connected geoengineering research and its governance to broader questions of professional authority, institutional capacity, and political legitimacy. It is important to understand such analogies as more than means of sense-making and opinion forming (cf. [Wibeck et al., 2015](#)). In the context of a deliberative exchange they are rhetorical devices strategically deployed to advance purposeful discursive objectives ([Schwarz-Plasch, 2016](#)). References to highly contentious issues such as unethical behaviour by journalists, racism amongst police officers, or deaths resulting from pharmaceutical testing, were used to alert interlocutors to the historical trajectories of more familiar social problems, and to shift the discussion away from matters of strictly ‘technical’ competence vis-à-vis geoengineering. Furthermore, the widespread use of analogies enabled participants to resist and reshape the framings offered to them by the facilitators, often making a forceful if implicit argument against reducing the object of deliberation to a matter of scientific research governance.

The diversity of arguments and preferences that emerged in our three workshops also points to the conceptual ambiguity that characterizes dimensions of scientific research, experimentation and governance that are often taken for granted or seen as self-evident. One important area of conceptual ambiguity concerns the question of

‘location’ or ‘scale’ in geoengineering experimentation. Considerations about whether an experiment would unfold ‘indoors’ or ‘outdoors’, for instance, or whether its size or scope constituted a ‘large’ or a ‘small’ intervention, frequently structured participants’ views on the most appropriate governance mechanism—indeed, on the very acceptability of the research in question. Yet in the full articulation of these arguments it became apparent that common descriptors of location or scale were fluid categories. Their meaning was qualified and modulated by reference to additional elements, and as a result was not reducible to any self-evident physical definition (cf. [Massey, 1992](#)). For instance, a ‘small’ experiment unfolding ‘indoors’ or in a contained space might be deemed unacceptable if it was thought to respond to the designs of a ‘maverick’ who was operating outside the controls of the scientific community. Or it could be considered too risky if it was deemed to eventually require, for the full satisfaction of its scientific validity, an irreversible intervention in the open environment, as some of the discussions on marine cloud brightening suggested. On the other hand, a ‘large’ experiment in air capture and storage conducted ‘outdoors’ was generally thought to present fewer governance challenges than smaller versions of the three other options, largely, it seems, because it was thought not to imply an irreversible intervention into the environment.

Scale and location, in other words, often seemed to function as proxies for a more capacious construct, namely the degree of *controllability* attributed to any given geoengineering experiment. This was indeed the crucial quality participants sought to characterize when they confronted specific research scenarios. Based on how it was articulated across the three workshops, controllability represented a complex, multifaceted quality. Participants drew on at least four dimensions of concern to define it: (1) level of containment; (2) uncertainty of experimental outcomes; (3) reversibility of environmental impacts; and (4) scientific purity.

Level of containment refers to those arguments that hinged on the degree of physical encapsulation of the experiment. This dimension was often framed in binary terms on the basis of whether the experiment in question would unfold ‘indoors’ or ‘outdoors’ (i.e. inside or outside a laboratory facility). Uncertainty of outcomes and impacts includes the multiple references that can be found in the discussions to the ability to predict or anticipate the results (and possible harms) of an experimental intervention. Reversibility of environmental impacts encompasses those claims that centred on the extent to which an experiment would entail a

permanent modification of the environment. Finally, under the rubric of scientific purity we classify those arguments that emphasized whether an experiment departed from the ideal of ‘pure’ or ‘basic’ research. Impure science, in this understanding, included here research conducted or sponsored by ‘mavericks,’ but also research carried out with a direct commercial intent. In fact, the question of ‘intent’ in geoengineering research arose consistently in relation to conceptions of scientific purity.

Under certain conditions these four dimensions can be aligned. An experiment conducted ‘in silico’ or in a contained setting, with relatively predictable outcomes and reversible environmental impacts, and thought to be carried out in the interests of ‘basic’ science, would in principle be deemed highly controllable and thus comparatively acceptable. In contrast, an ‘in vivo’ experiment unfolding in an uncontained setting, with relatively more unpredictable outcomes and potentially irreversible impacts, and conducted in the interests of ‘applied’ science or with commercial intent, would be considered least controllable and acceptable. Yet more often than not participants had to grapple with manifold inter-relations between these four dimensions of controllability, leading to ambivalent, highly qualified assessments of the acceptability of certain forms of research.

This finding resonates with other recent social-scientific work on geoengineering experimentation and its public legitimacy. In a series of focus groups with Japanese citizens, for instance, [Asayama et al. \(2017\)](#) find a significant degree of ambiguity and ambivalence with regards to the possibility of conducting field trials of stratospheric aerosol injection. Participants in this exercise characterized ‘controllability’ by reference to at least three distinct criteria: technical reversibility, institutional controllability, and spatial boundedness. The fact that citizens employ complex, multidimensional criteria in evaluating experimental proposals means that we need more clarity in the definition of what is entailed by ‘geoengineering research’ ([Asayama et al., 2017](#)). This need for accountability extends to geoengineering research conducted indoors, even when it is limited to the design and conduct of computer simulations. As [Thilo Wiertz \(2015\)](#) has noted with respect to the use of simulations in the development of solar geoengineering options, computer models often represent “the primary space” in which social visions of a geoengineered future are articulated and tested, and as such require an appropriate level of public scrutiny (see also [Edwards, 2011](#)).

5. Conclusions

The ability of lay citizens to productively deliberate on the dilemmas posed by geoengineering has been demonstrated by a multitude of consultation exercises conducted over the last decade. Our exercise validated this conclusion: despite very little (if any) prior knowledge of the matter at hand and with the help of a cursory introduction to the topic, a vast majority of participants across the three groups engaged actively and intelligently with multiple geoengineering research and governance proposals, putting forward arguments that balanced multiple criteria of relevance.

Our experimental approach created a diverse set of deliberative conditions and decision-making processes in order to expand the range of contexts where actors discuss geoengineering, beyond the traditional model of egalitarian-consensual deliberation that has traditionally dominated managed forms of public engagement with emerging technologies. Notwithstanding the limitations noted earlier, we believe our design allowed the articulation of a greater variety of viewpoints and lines of argumentation – for, against, and often critically ambivalent about specific geoengineering proposals. Investigating how the particular conditions of debate and decision-making might impact the substance of deliberation on geoengineering will require further developments of the method. This can include the use of control groups, but also the refinement of facilitation techniques. In devising styles of facilitation for the majoritarian and individualist groups, for instance, we

encountered a paucity of relevant sources, due to the preponderance of egalitarian-consensual forms of deliberation in the fields of science communication and public engagement with science. Yet any attempts to improve the method along these lines will have to take into account the emergent properties of groups created for research purposes. As several scholars have noted, and as we experienced in our investigation, publics created explicitly for the purpose of deliberating display forms of sociability that exceed the formalizations implicit in any particular design; they express an ‘eventfulness’ proper to the moment of deliberation that precludes the ability to fully characterize *a priori* the variables in play (cf. [Michael 2012](#); [Chilvers and Kearnes 2016](#); [Lezaun et al., 2016](#); [Pritchard and Gabrys 2016](#)).

Our experimental deliberative exercise yielded a series of relevant observations. Perhaps the most significant one is that the perceived controllability of a geoengineering experiment is central to its public acceptability, but that controllability itself is a multidimensional construct. Participants introduced four key dimensions to characterize the degree of controllability of geoengineering research: (1) experimental containment; (2) outcome uncertainty; (3) environmental reversibility; and (4) scientific purity. While controllability has been noted as a crucial nexus of public concern regarding controversial technologies, and indeed a ‘control dilemma’ might be said to define the trajectory of all emerging technologies ([Collingridge, 1982](#)), what is clear from our research is that controllability is itself a composite construct and a multifaceted evaluative register. In other words, citizens draw on highly specific technical, institutional, moral and even epistemological criteria to decide whether a particular innovation trajectory is more or less controllable, and the manner in which they will combine those criteria is specific to the question at hand and as a result difficult to predict in advance.

For this reason, it would be naïve to reduce the governance of geoengineering research to any single parameter of the research in question. Thus, positions that argue that researchers can ‘start small’ even before the governance challenges are fully worked out (see, for example, [Parson and Keith \(2013\)](#) and [Long et al. \(2015\)](#)), or that ‘indoor’ experiments can proceed with little need for transparency or public accountability, overlook the complex discursive processes by which the parameters of controllability come to be defined (cf. [Dilling and Hauser, 2013](#); [Dilling and Hauser, 2013](#); [Stilgoe, 2013](#)). ‘Control’ emerged in our deliberations as a function not simply of the physical location and spatial scope of the proposed intervention, but also of the uncertainty associated with research outcomes, the reversibility of experimental effects, or the intentionality attributed to the actors involved in the research endeavour.

In sum, our exercise disclosed the variety of criteria citizens employ in evaluating the acceptability of geoengineering research, and the intricate nature of the arguments they develop for or against experimental interventions in this area. This fact raises the stakes for the development of appropriate mechanisms for the social appraisal of geoengineering research, but also opens the field in terms of the factors that can be brought to bear in such an appraisal.

Funding

This research received support from the UK Economic and Social Research Council (ESRC) and the Arts and Humanities Research Council (AHRC) under the Climate Geoengineering Governance project (Grant ES/J007730/1). Further support was provided by the V. K. Rasmussen Foundation and ClimateWorks under the project Greenhouse Gas Removal Instruments & Policies project (GRIP).

Acknowledgments

We are grateful to Steve Rayner for his advice on the design of the workshops and his comments on our interpretation of the results, and to Jack Stilgoe, Jason Chilvers and Stefan Schäfer for their thoughts on an

early version of the paper. We would like to thank the six reviewers for *Global Environmental Change* for forcing us to think harder about the implications of this study.

References

- Asayama, S., Sugiyama, M., Ishii, A., 2017. Ambivalent climate of opinions: tensions and dilemmas in understanding geoengineering experimentation. *Geoforum* 80, 82–92.
- Bellamy, R., Hulme, M., 2011. Beyond the tipping point: understanding perceptions of abrupt climate change and their implications. *Weather Climate Soc.* 3, 48–60.
- Bellamy, R., Lezaun, J., 2017. Crafting a public for geoengineering. *Publ. Understanding Sci.* 26, 402–417.
- Bellamy, R., Chilvers, J., Vaughan, N., Lenton, T., 2012. A review of climate geoengineering appraisals. *WIREs Climate Change* 3, 597–615.
- Bellamy, R., Chilvers, J., Vaughan, N., 2016. Deliberative Mapping of options for tackling climate change: citizens and specialists ‘open up’ appraisal of geoengineering. *Publ. Understanding Sci.* 25, 269–286.
- Bellamy, R., 2016. A sociotechnical framework for governing climate engineering. *Sci. Technol. Hum. Values* 41, 135–162.
- Bodle, R., Oberthür, S., Donat, L., Homann, G., Sina, S., Tedsen, E., 2014. Options and Proposals for the International Governance of Geoengineering. Ecologic Institute, Berlin.
- Burns, W.C., Flegal, J.A., 2015. Climate geoengineering and the role of public deliberation: a comment on the us national academy of sciences’ recommendations on public participation. *Clim. Law* 5 (2–4), 252–294.
- Chilvers, J., Kearnes, M., 2016. Remaking Participation: Science, Environment and Emergent Publics. Routledge, London.
- Collingridge, D., 1982. *The Social Control of Technology*. St Martin’s Press, New York.
- Corner, A., Parkhill, K., Pidgeon, N., Vaughan, N., 2013. Messing with nature? Exploring public perceptions of geoengineering in the UK. *Global Environ. Change* 23, 938–947.
- Dake, K., 1991. Orienting dispositions in the perception of risk: an analysis of contemporary worldviews and cultural biases. *J. Cross Cult. Psychol.* 22, 61–82.
- Dilling, L., Hauser, R., 2013. Governing geoengineering research: why, when and how? *Clim. Change* 121, 553–565.
- Douglas, M., Wildavsky, A., 1982. *Risk and Culture: an Essay on the Selection of Technological and Environmental Dangers*. University of California Press, London.
- Finucane, M.L., 2002. Mad cows, mad corn and mad communities: the role of socio-cultural factors in the perceived risk of genetically-modified food. *Proc. Nutr. Soc.* 61 (01), 31–37.
- Hulme, M., 2014. *Can Science Fix Climate Change? A Case Against Climate Engineering*. Polity, Cambridge.
- Kahan, D., Braman, D., Slovic, P., Gastil, J., Cohen, G., 2009. Cultural cognition of the risks and benefits of nanotechnology. *Nat. Nanotechnol.* 4, 87–90.
- Kahan, D., Jenkins-Smith, H., Tarantola, T., Silva, C., Braman, D., 2015. Geoengineering and climate change polarization: testing a two-channel model of science communication. *Ann. Am. Acad. Political Soc. Sci.* 658, 192–222.
- Krueger, R., 1994. *Focus Groups: a Practical Guide for Applied Research*. Sage, Thousand Oaks, CA.
- Lewin, K., Lippit, R., White, R., 1939. Patterns of aggressive behaviour in experimentally created social climates. *J. Soc. Psychol.* 10, 271–301.
- Lezaun, J., Calvillo, N., 2014. In the political laboratory: kurt Lewin’s atmospheres. *J. Cultural Econ.* 7 (4), 434–457.
- Lezaun, J., Marres, N., Tironi, M., 2016. Experiments in participation. *The Handbook of Science and Technology Studies*. pp. 195.
- Long, J., Loy, F., Morgan, G., 2015. Start research on climate engineering. *Nature* 518, 29–31.
- Macnaghten, P., Szerszynski, B., 2013. Living the global social experiment: an analysis of public discourse on solar radiation management and its implications for governance. *Global Environ. Change* 23, 465–474.
- Massey, D., 1992. *Space, Place and Gender*. University of Minnesota Press, Minneapolis.
- Merk, C., Pönitzsch, G., Kniebes, C., Rehdanz, K., Schmidt, U., 2015. Exploring public perception of stratospheric aerosol injection. *Clim. Change* 130, 299–312.
- Michael, M., 2012. What are we busy doing? Engaging the idiot. *Sci. Technol. Human Values* 37 (5), 528–554.
- Natural Environment Research Council, 2010. *Experiment Earth? Report on a Public Dialogue on Geoengineering*. (Available at nerc.ac.uk/about/consult/geoengineering.asp).
- National Research Council, 2015. *Climate Intervention: Reflecting Sunlight to Cool Earth*. National Academies Press, Washington, DC.
- Parker, A., 2014. Governing solar geoengineering research as it leaves the laboratory. *Phil. Trans. R. Soc. A* 372 (2031), 20140173.
- Parkhill, K.A., Pidgeon, N., 2011. *Public Engagement on Geoengineering Research: Preliminary Report on the SPICE Deliberative Workshops*.
- Parson, E., Keith, D., 2013. End the deadlock on governance of geoengineering research. *Science* 339.
- Peters, E., Slovic, P., 1996. The role of affect and worldviews as orienting dispositions in the perception and acceptance of nuclear Power. *J. Appl. Soc. Psychol.* 26 (16), 1427–1453.
- Pidgeon, N., Parkhill, K., Corner, A., Vaughan, N., 2013. Deliberating stratospheric aerosols for climate geoengineering and the SPICE project. *Nat. Clim. Change* 3, 451–457.
- Pritchard, H., Gabrys, J., 2016. From citizen sensing to collective monitoring: working through the perceptive and affective problematics of environmental pollution. *Geohumanities* 2 (2), 354–371.
- Rayner, S., Cantor, R., 1987. How fair is safe enough? The cultural approach to societal technology choice. *Risk Anal.* 7, 3–9.
- Rayner, S., Heyward, C., Kruger, T., Pidgeon, N., Redgwel, C., Savulescu, J., 2013. The oxford principles. *Climatic Change* 121, 499–512.
- Rayner, S., 1991. A cultural perspective on the structure and implementation of global environmental agreements. *Eval. Rev.* 15, 75–102.
- Schwarz-Plaschg, C., 2016. Nanotechnology is like... The rhetorical roles of analogies in public engagement. *Public Underst. Sci.* <http://dx.doi.org/10.1177/0963662516655686>.
- Stilgoe, J., Watson, M., Kuo, K., 2013. Public engagement with biotechnologies offers lessons for the governance of geoengineering research and beyond. *PLoS Biol.* <http://dx.doi.org/10.1371/journal.pbio.1001707>.
- Stilgoe, J., Lock, S., Wilsdon, J., 2014. Why should we promote public engagement with science? *Public Underst. Sci.* 23, 4–15.
- Stilgoe, J., 2015. *Experiment Earth: Responsible Innovation in Geoengineering*. Routledge.
- Stirling, A., 2007. Risk, precaution and science: towards a more constructive policy debate. *EMBO Rep.* 8, 309–315.
- Tollefson, J., 2012. Ocean fertilisation project off Canada sparks furore. *Nature* 490, 458–459.
- Wibeck, V., Hansson, A., Anshelm, J., 2015. Questioning the technological fix to climate change – lay sense-making of geoengineering in Sweden. *Energy Res. Soc. Sci.* 7, 23–30.
- Wiertz, T., 2015. Visions of climate control: solar radiation management in climate simulations. *Science. Technol. Human Values.* <http://dx.doi.org/10.1177/0162243915606524>.
- Wilsdon, J., Willis, R., 2004. *See-through Science: Why Public Engagement Needs to Move Upstream*. Demos, London.
- Wynne, B., 1992. Uncertainty and environmental learning: reconceiving science and policy in the preventive paradigm. *Global Environ. Change* 2, 111–127.