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‘Experiment Earth?’ Reflections on a public dialogue on geoengineering

Adam Corner, Karen Parkhill and Nick Pidgeon

School of Psychology
Cardiff University

WORKING PAPER

Corresponding author: Adam Corner, School of Psychology, Cardiff University, Cardiff.
corneraj@cardiff.ac.uk

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Abstract

As the window of opportunity for mitigating dangerous climate change grows ever smaller, proposals to use large scale technologies to control the earth's climate – known collectively as geoengineering – have started to be taken seriously by scientists and policy makers in the UK and elsewhere. During early 2010, the first series of major UK public engagement events on geoengineering took place – and were described in a report titled 'Experiment Earth?' The events were designed to provide an opportunity for members of the public to engage with these emerging technologies at a very early stage. More specifically, they aimed to gauge the public's views on the future of research into geoengineering. This working paper reflects on the framing, process, methods and findings of the public dialogue, and offers a set of recommendations for future public engagement on this topic.

1. Introduction: From Climate Change to Climate Control

1.1 Avoiding dangerous climate change: is mitigation and adaptation enough?

The basic question of whether human activities are altering the climate is no longer seriously contended (IPCC, 2007; Royal Society, 2010). The rapidly increasing levels of greenhouses gases attributable to the burning of fossils fuels have already warmed the earth by approximately 0.8 degrees Celsius since the industrial revolution. Even if no more greenhouse gases were ever released into the atmosphere, at least another 0.7 degrees of warming is likely to take place this century due to the time delay between the release of greenhouse gases and their warming effect. The effects of climatic warming are already visible in the arctic, where levels of summer sea ice are decreasing (ACIA, 2004).

Predicting what will happen in the future is more difficult than documenting what has happened in the past. Exactly how much the earth will warm, exactly what the effects will be, and exactly where the impacts will be felt are ongoing questions that will never be fully answered. Uncertainty will remain an integral part of science in general, and climate science in particular (Budescu, Broomell & Por, 2009; Pollack, 2005; Poortinga et al, 2001). However, there is a remarkable degree of agreement among scientists that left unchecked, climate change will have overwhelmingly adverse effects on human and natural systems – including increased floods, droughts and extreme weather events, lowered productivity from many large areas of existing farmland, ocean acidification and its associated effects on coral reefs and the biodiversity they sustain, migration due to climatic changes and conflict over dwindling resources (IPCC, 2007).

Although the term is highly contested (Dessai et al., 2004; Anderson & Bows, 2008; 2011), attention has focused on what would constitute 'dangerous' climate change – broadly interpreted to indicate the point at which the effects attributable to climatic changes become unacceptably negative for global society (Lorenzoni, Pidgeon & O'Connor, 2005; Oppenheimer, 2005). A loose political consensus has formed around the idea that a rise of more than two degrees Celsius in global temperatures (relative to pre-industrial revolution temperatures) constitutes dangerous climate change. As a rise of 1.5 degrees is now all but inevitable, there is an extremely small window of opportunity in which to prevent dangerous climate change. In this context, with the global population and per-capita levels of greenhouse gases emissions continuing to rise at unprecedented rates, geoengineering has started to be considered as a means of responding to dangerous climate change alongside existing methods of mitigation and adaptation.

1.2 Geoengineering

The term 'geoengineering' is used to refer to a wide range of proposals to use large-scale technologies to slow down and/or reverse the effects of anthropogenic climate change. It includes a diverse range of technologies, some of which are familiar and many that have never been tested on a meaningful scale. The link between these technologies is that they all have the potential to be deployed in order to control or alter the earth's climate. Very broadly, geoengineering technologies fall into two categories – proposals to remove a proportion of Carbon Dioxide from the atmosphere (Carbon Dioxide Removal – CDR) and proposals to reflect a proportion of sunlight away from the earth, thereby lowering global temperatures (Solar Radiation Management – SRM). The technologies implicated in these proposals vary enormously on many important dimensions. Some are well-understood but ineffectual unless deployed on an incredibly large scale (e.g. reforestation programmes to absorb carbon dioxide). Others are likely to be highly effective at reducing global temperatures but carry a high risk of unintended effects (e.g. the releasing of reflective sulphur particles into the stratosphere to reflect sunlight). The estimated cost, reversibility and speed with which the technologies can be implemented are also critical factors for evaluating geoengineering proposals (Royal Society, 2009).

While questions about the efficacy and safety of these putative technologies are hugely important, proposals to geoengineer the climate represent much more than simply a set of technologies with attendant risks and benefits. The idea of geoengineering – the concept that we might intentionally alter the earth's climate – is riddled with social, moral, legal and ethical uncertainties arguably more profound and challenging than any of the questions relating to the technical feasibility of manipulating the climate (Corner & Pidgeon, 2010; Gardiner, 2011; Royal Society, 2009). The importance of engaging with the many non-technical questions raised by geoengineering has been acknowledged by many authors. Most notably, the Royal Society report "Geoengineering the climate: Science, governance and uncertainty", stated that the future acceptability of geoengineering would be "determined as much by social, legal, and political issues as by scientific and technical factors" (Royal Society, 2009). Public dialogue, as part of these accompanying socio-cultural and ethical dimensions to technocratic discourses, was thus deemed of critical importance.

1.3 Upstream public engagement

Many new technologies are embraced by society with very little public debate or controversy, but others – like agricultural biotechnology (Bauer and Gaskell, 2002), or nuclear power and radioactive waste (Rosa and Clark, 1999) – raise significant social and ethical questions. Geoengineering looks likely to join this list of contested technologies, because of its potential for unintended global environmental consequences, ethical sensitivities, and the complex trans-boundary governance issues it raises (Corner & Pidgeon, 2010; Pidgeon et al, in press; also see Royal Society, 2009; Rayner et al, 2010).

A technology can be said to be upstream if significant research and development has not yet begun, public controversy about the topic is not currently present, and entrenched attitudes or social representations have not yet been established (Rogers-Hayden and Pidgeon, 2007). All of these criteria apply to geoengineering's current position (see Corner & Pidgeon, 2010), as it is currently in a pre-development phase where many of its technical aspects – including questions around effectiveness, cost and risks – are highly uncertain. Geoengineering is therefore a prime example of an upstream technology – and there is a significant body of work describing and detailing 'best practice' strategies for upstream public engagement (see, e.g., Corner & Pidgeon, 2010; Rogers-Hayden and Pidgeon, 2007; Wilsdon and Willis, 2004).

Initial interest in the public understanding of new or controversial scientific topics focused on the idea that public opposition to science and technology was linked to a 'deficit' of knowledge that could be addressed by public engagement (Felt & Fochler, 2010; Hagendijk & Irwin, 2006; Irwin & Wynne, 1996; Pidgeon et al., 2008; Renn, Webler & Wiedemann, 1995; Wynne, 2007). It was assumed that if only people knew more about a technology, they would come to see its benefits as outweighing its risks. This ‘deficit hypothesis’ has been discredited by empirical evidence – multiple studies have failed to find a straightforward link between a lack of knowledge about science and opposition to it (Sturgis & Allum, 2004). But the deficit approach has also fallen out of favour for another reason – it embodies the old-fashioned idea that public engagement is a one-way process, rather than a dialogue between scientists and the public.

It is now widely acknowledged that good practice in upstream engagement involves not only the transmission of information from ‘experts’ to members of the public, but also a process of dialogue between scientists and the public. Upstream topics like geoengineering are of particular interest because they are not yet subject to entrenched attitudes or social representations (Rogers-Hayden & Pidgeon, 2007), and this means that public attitudes and views can legitimately be fed into decision making processes around the development and regulation of geoengineering. Interest in upstream engagement – and the broader notion of ‘responsible innovation’ – in Europe can be partly attributed to the widely held perception that public engagement over agricultural biotechnology (i.e. GM) resulted in something of a ‘backlash’. Wilsdon and Willis (2004) argued that public engagement on GM began too late for public input to impact on research and development. Following this line of reasoning, in order to be considered legitimate upstream engagement must be conducted before major investment decisions have been made, and relate more to values and notions of progress than products and processes of technical development (Rogers-Hayden & Pidgeon, 2007).

The central purpose of the current paper is to reflect on the ‘Experiment Earth?’ public dialogue events (and accompanying report) – the first major piece of upstream engagement on geoengineering. Having introduced the topics of climate change, geoengineering and the practice of upstream public engagement, we now offer an analysis of the design and methodology of the ‘Experiment Earth?’ events, the way the subject of geoengineering was presented (or ‘framed’), and the findings in the final report. The aim of this reflective paper is to allow lessons to be learnt from the ‘Experiment Earth?’ public dialogue process, so that future public engagement on geoengineering can be as best-informed by previous experience as possible. It should be emphasised from the outset that our reflections on ‘Experiment Earth?’ are not intended to represent a negative assessment of it. We consider ‘Experiment Earth?’ to have been a successful public engagement exercise, as the official evaluation report that accompanied the dialogue process is testament to (Collingwood Environmental Planning Limited, 2011).

2. Reflections on the design and methodology of ‘Experiment Earth?’

2.1 *Description of the ‘Experiment Earth?’ public dialogue events*

Representing the first major attempt at public engagement on geoengineering, during March and April in 2010, a series of public dialogue events were held in the UK, funded by the Natural Environment Research Council (NERC) and other partners[1]. The events were designed to provide an opportunity for members of the public to engage with these emerging technologies at a very early stage. More specifically, they aimed to gauge the public’s views on the future of research into geoengineering. As the funding body most likely to commission and support geoengineering research, NERC sought to establish public views on the moral, ethical and societal implications of funding research into geoengineering. The events were undertaken by the social research company Ipsos MORI and partners Dialogue by Design – specialists in public engagement. The resulting report was titled “Experiment Earth? Report on a Public Dialogue on Geoengineering” (Ipsos MORI, 2010). A further evaluation report, focussing on the extent to which the project achieved its stated aims, was conducted by Collingwood Environmental Limited (2011).[2]

A total of seven public dialogue events were held – two in Birmingham, Cardiff and Cornwall (Events 1 and 2), and a reconvened event (with a small subset of the

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[1] Other partners included Sciencewise, the Royal Society and the Living With Environmental Change Programme.

[2] The Collingwood report had a brief that was quite distinct from the goal of the current paper. It was designed to establish whether ‘Experiment Earth?’ had met its own objectives, including conformity to Sciencewise-ERC principles of good public engagement practice, and participants’ satisfaction with the process. The overall objectives of the project were considered to have been met and participants were generally satisfied with their involvement. However several ‘learning points’ were identified, and where these learning points overlap with the analyses offered in this paper, we draw on them to support our reflections.

participants from each of the three previous locations) in Southampton (Event 3). Around 30 people attended each event, with approximately 85 participants in total.[3]

2.2 The quality of the information provided

The order in which participants received information and materials at each of the three events is described in detail in the appendices of the ‘Experiment Earth?’ report – only a very short summary is provided here. In Event 1, an initial presentation about climate change led directly into the introduction of the topic of geoengineering (alongside mitigation and adaptation), and participants were then presented with the pros and cons of nine geoengineering technologies by rotating small groups around each technology. A further presentation identified strengths and weaknesses of the technologies (in terms of effectiveness, safety and value for money). Having been provided with these criteria, participants were then asked to map the technologies against them. As a post-event task, participants were asked to think more about the subject and come up with one question they would ask before initiating research on geoengineering. It is important to note that by the end of Event 1, there had been no formal mention of social, ethical or governance issues – although participants may have independently touched on these in discussions.

In Event 2, following a summary of Event 1 and the nine technologies, a presentation on ‘ethics in science’ was made. Four ‘scenarios’ were then given to participants based on a different technology, and people were asked to consider these scenarios using ethical criteria. Lastly, participants saw short films demonstrating a range of moral arguments surrounding geoengineering from ‘talking head’ experts.[4]

In Event 3, participants were given an opportunity to summarise the conclusions from their regional groups, heard more detailed presentations about specific geoengineering

[3] There were also a series of other events that formed part of the Experiment Earth process – including discussion meetings with people likely to be at risk of flooding, open access events for people to drop in and talk about climate change and geoengineering, and an online survey. These aspects of the project are not discussed in the current report.
[4] Two of the authors of this paper were directly involved in this process. Nick Pidgeon was part of the ‘Experiment Earth?’ steering group, and was present as an expert participant at the Cardiff event. Adam Corner provided a pre-recorded short film on the social and ethical aspects of geoengineering for Event 2.

technologies and were provided with information about how NERC makes funding decisions (and how 'Experiment Earth?' would feed into future decisions on geoengineering).

Based on the materials in the appendix of the 'Experiment Earth?' report and recordings of Event 3, it seems clear that the level of information provision and debate facilitation was very high (underscored by the generally positive assessment in the Collingwood evaluation report, 2011). Significant efforts were made to present information to participants in as unbiased and neutral way as is possible, and by the third event, participants were engaging with the issues raised by geoengineering using a high degree of sophistication. In terms of facilitating a two-way process of dialogue, there were ample opportunities for participant-led discussions. However, there were also elements of the information provision process that could be improved in subsequent public engagement initiatives.

One finding documented in the 'Experiment Earth?' report was that some participants struggled to understand the complexities of climate science and geoengineering technologies. A similar point was raised in the Collingwood Environmental Planning (2011) evaluation report: although the materials presented to participants were generally assessed to be of high quality, some participants expressed concerns that the material was very 'science-heavy'. A possible explanation for this is that the presentations on climate change and geoengineering were quite technical, containing graphs and technical figures. While it is neither possible nor desirable to exclude technical terminology from a discussion of geoengineering, a less technical approach may have enhanced (rather than hindered) the engagement process. For example, in the initial presentation used to introduce the idea of accumulating carbon dioxide in the atmosphere causing climate change, terms such as 'parts per million' were introduced very early on. Similarly, quite technical-looking graphs depicting temperature increases and levels of greenhouse gas emissions formed a significant part of the presentation[5].

[5] Although the use of graphs is not necessarily problematic – in fact, they can be valuable explanatory tools – the particular graphs used here required a fairly high level of expertise to interpret unaided. For example, the first graph shown to participants was labelled 'Anomaly in degrees C compared to 1961-1990 average'.

Given what is known about the complex relationship between scientific knowledge and perceptions of risks and benefits, it is not necessarily a 'flaw' in the design of 'Experiment Earth?' that participants expressed a degree of confusion about technical details. But following this logic also suggests that an overly technical presentation of information is unlikely to be helpful for engagement – it is not necessary to provide much in the way of technical information in order for people to deliberate about technologies. This is because debates about technologies are only partially about the technical risks and benefits they pose – the social values and cultural worldviews that particular instantiations of technologies embody are also important (see, e.g., Stirling, 2008).

Complementing our analysis, one of the learning points identified in the Collingwood (2011) evaluation report was that members of the public should not be expected to 'become scientists' in dialogue processes such as these. Instead, participants should be encouraged to bring their own (typically non-technical) expertise to the project. While this is a separate issue to participants' comprehension of specific technical terms, the two issues are related: over-reliance on technical terminology sends a strong signal to participants that they should be 'thinking like scientists', when in fact it is their social intelligence that is more valuable.

One additional consideration about the level of information provided to participants is that costs were estimated for putative technologies – with some described as relatively inexpensive ways of reducing carbon dioxide levels, and others labelled as relatively expensive. While it is certainly true that different geoengineering technologies will have quite different costs associated with them, the technologies are currently at such early stages of development that cost estimates are indicative at best (Royal Society, 2009). This suggests that undue emphasis should not be placed on the financial comparability of competing technologies until more information is available.

2.3 The order in which the information was presented

Although the stated aim of the 'Experiment Earth?' project was to identify the moral, ethical and societal implications of funding research into geoengineering, an explicit discussion of these issues did not take place until Event 2. The balance of

‘Experiment Earth?’ was weighted very heavily towards the physical risks and benefits of the geoengineering technologies discussed. Focussing so strongly on the pros and cons of the various technologies is likely to have framed subsequent discussions in a particular way. An intuitive question for participants to ask – whether or not it was explicitly framed in this way – would have been “which of these technologies is the one with the most promise?”

This is only one possible question that could be asked about geoengineering, and it is one that is very technology-focused. Crucially, it is a question that one would ask once other more basic answers had been established – for example, is the intentional manipulation of the climate ever ethically acceptable? To the extent that participants in Event 1 of ‘Experiment Earth?’ were not encouraged to ask these questions prior to considering the pros and cons of individual technologies, an important opportunity for gathering public opinion on the concept of geoengineering may have been missed.

There is some evidence from the audio recordings of Event 3 that participants were not explicitly encouraged to identify the ‘best’ or ‘worst’ technologies – an expert delivering a presentation to the whole group clarified the aim of the dialogue in the following way:

> “We’re not hoping you’re going to tell us ‘you should be doing biochar’ or ‘you should be doing space mirrors’ or whatever, but it’s that sense of…of what parameters we’d use to decide what to do, and in particular if there are things that you think we should not be doing because you think the risks are too high”. (Male expert in Event 3)

Communicating this sentiment to participants is important – experience with other emerging technologies suggests that the particular application that a technology is instantiated in matters a great deal to public opinion of the underlying technology. For example, Bauer and Gaskell (2002) showed that people were more positive about biotechnology for human health applications compared to agricultural uses. Similarly, in deliberative work discussing nanotechnology with members of the public in both the UK and USA, energy applications were seen as relatively unproblematic compared to health and human enhancement issues, with the latter felt to raise particular ethical and societal questions (Pidgeon et al, 2008).

2.4 The *'climate catastrophe' framing*

In addition to the heavy early focus on technical risks and benefits, the 'Experiment Earth?' facilitators and experts explicitly used the notion of a 'climate catastrophe' or 'climate crisis' on several occasions. This is the idea that geoengineering may be necessary to deal with a climatic emergency, especially if other options have failed. In the audio recordings of Event 3, several of the experts prompted discussion of the technologies using questions explicitly linking geoengineering to a climatic emergency. For example, one expert asked a small group of participants "What if life gets so bad that we need an emergency solution, isn't it worth researching what to do now?" (Expert in Event 3).

It is difficult not to answer this question in the affirmative – few would seek to deny the knowledge necessary to deal with a scenario where life is so bad that an emergency solution is needed. The question is whether this is a reasonable framing to provide people with. Although the notion of climatic 'tipping points' (non-linear, abrupt and effectively irreversible changes in the climatic system) are a genuine cause for concern, there is an ongoing debate about whether it is possible to differentiate a 'climate crisis' from the more mundane notion of climatic change (see, e.g., Hulme, 2009). In fact, the very notion of 'dangerous' climate change is contested – for some nations (e.g. the low-lying islands that comprise the Maldives), a rise in global temperatures of only 1.5 degrees Celsius would constitute a major risk. For others, a global change of 2 degrees is unlikely to pose insurmountable problems (at least at a national level).

It is true that the consideration of geoengineering techniques is borne out of concern that current mitigation and adaptation strategies will not be enough to prevent dangerous climate change. It is also true that there is some scope for a large-scale technological intervention to act as a rapid response to changes in the climate. But presenting geoengineering to people as a possible response to a climatic emergency is problematic, especially if linked to the need to conduct research at an early stage: It provides a very strong framing of necessity, which is likely to have artificially enhanced the acceptability of conducting research into these technologies.

2.5 Use of imagery

Many geoengineering technologies do not yet exist. This poses a challenge for using imagery to depict certain technologies, as visual images are only artists' impressions of what scientists think the technologies will ultimately look like. In 'Experiment Earth?' several images of geoengineering technologies were used to help participants understand what they might look like if they were deployed. As an example, we focus on the image used to depict air capture (Image 1).

Image 1: An artist's impression of how air capture could be deployed. Image from the handouts provided to participants in 'Experiment Earth?' Event 1.

The 'Experiment Earth?' team explained that the image used to depict air capture was an artists' impression rather than an actual photo. However, the image was obviously designed to be indicative of a possible use of this technology – otherwise it would not have been used. Visual images convey a great deal of information, which is why they are useful as explanatory aides. But they can also convey potentially misleading information (as the 'Experiment Earth?' authors acknowledge with regards to the image of biochar, which seemed to be interpreted as evidence that it was a space-effective way of geoengineering). The image used to depict air capture in 'Experiment Earth?' contained a great deal of information that did not relate directly to the expected physical appearance of air capture technology. The image shows air capture technology interspersed with wind turbines, dwarfed in size by the length of the turbines' blades. The air capture vents and wind turbines are shown unrealistically close to a motorway – but the overriding impression is one of normality. The viewer of the picture is invited to imagine a world in which air capture blends seamlessly into the existing transport infrastructure (more seamlessly, in fact, than sources of renewable energy like wind turbines). It is a world in which people still drive cars – one that looks much the same as the present day.

Perhaps a future that involves geoengineering will resemble the one depicted in the image – but it is an almost utopian vision of how geoengineering technologies will slot into society. Given that the purpose of public dialogue events like 'Experiment Earth?' is to elicit – rather than provide – these kinds of judgments, it seems important to consider carefully the imagery used in public engagement events on geoenegineering in the future.

2.6 Use of language

When discussing emergent technologies and scientific development, it is a difficult and delicate exercise to express their potential benefits without unintentionally implying that these (putative) benefits are in fact concrete, provable advantages. In the 'Experiment Earth?' materials, an advantage stated for biochar was that it 'addresses the cause of climate change directly'. Whilst it certainly could aid in the reduction of CO2 held in the atmosphere and oceans, biochar on its own is unlikely to ever be able to be deployed at a scale which could deal with all cumulative emissions. It is unclear how much emphasis was placed on the uncertainties related to future cumulative emissions and how these may impact on the effectiveness of all forms of geoengineering – the more CO2 that is released into the atmosphere, the less scope there is for biochar (or any other approach) to make a substantial impact on overall atmospheric levels. But such a framing also risks obfuscating the reasons that green house gas emissions are so high in the first place (including industrialisation, the embeddedness of socio-technical systems, high-energy lifestyles and behaviours, etc). Yes, biochar removes CO2 from the atmosphere and stores it in the ground – and so in a narrow sense, it addresses the cause of climate change (CO2) directly. But why is there so much CO2 in the atmosphere? A presentation of CDR technologies as addressing the root cause of climate change may engender the seductive belief that geoengineering could 'solve' climate change irrespective of conventional forms of mitigation and adaptation. As with the use of imagery, there is a danger of a 'business as usual' approach being unwittingly promoted through particular linguistic presentations. It may be that participants subscribe to this view – but this is for them to decide, not for public engagement researchers to prompt.

3. Reflections on the 'Experiment Earth?' findings

3.1 *Key findings from 'Experiment Earth?'*

A summary of 'Experiment Earth?' participants' views about specific geoengineering technologies is provided in Table 2.

Carbon Dioxide Removal (CDR)	Solar Radiation Management (SRM)
Afforestation and Biochar. Consistently highlighted as preferred methods. Seen as 'natural' approaches and preferred for this reason.	**SRM** gained less support overall, as it was perceived not to tackle the root cause of climate change (greenhouse gasses).
Iron Fertilisation and Ocean Liming. Level of support for ocean-based methods was consistently low, although at the final event people were more prepared to consider these.	**Cloud Whitening** and **Sulphate Particles** were the most positively received (particularly the former) of the generally disliked SRM technologies, but were not endorsed by a majority.
Air Capture. Support for this increased throughout the deliberative events. Could be carried out at a local level without international regulation, and the results seen more quickly than afforestation.	**Mirrors in Space** were seen as expensive and risky, while **White Roofs** were viewed as likely to be ineffective and infeasible.

Table 2: 'Experiment Earth?' Participants' Views on Different Geoengineering Proposals
Source: adapted from Ipsos-Mori (2010, p.2)

Participants were encouraged to elucidate 'underlying principles' that determined the acceptability of different geoengineering proposals. The key criteria the participants generated are displayed in Table 3:

Principle	Rationale
Effects on Mitigation	Geoengineering should not conflict with, and wherever possible augment, mitigation efforts
Supporting ‘Natural’ Processes	Most participants believed that natural systems were balanced and self-contained. An affective judgement, most believed that geoengineering should be considered in terms of its impacts on natural systems, and this formed an important context to their other opinions on geoengineering
Controllability	Scientists should not interfere with complex natural systems without detailed assessments of consequences.
Reversibility	Scientists needed to retain control and be able to ‘switch off a project’, and therefore needed to be sure that research and deployment could be reversed if necessary. Small steps might help to achieve this.
Effectiveness	Scientists should weigh up core benefits against costs, taking account of the amount of CO2 removed and overall global temperature reductions. A range of costs should be considered (carbon, financial, future, opportunity, investment).
Timing	Governments and other authorities should set a timetable for action, and establish when the need for action would become urgent (i.e. define a ‘climate emergency’). The public should be informed, so they can give or withdraw support, as new information about this is gained.
Regulation and Equity	Where there were trans-boundary implications international governments should come together to decide on regulation, to ensure that effects and benefits are distributed equitably across the globe. The long term-consequences ought to be considered, as should the voices of those in the developing world.

Table 3: ‘Experiment Earth?’ Participants’ Views on Geoengineering Research and Research Governance

Source: adapted from Ipsos-Mori (2010, p.2-3)

Given the constraints in accessing the primary data from 'Experiment Earth?' we sought to comment only briefly on the key findings in the current paper.

3.2 Differences between technologies and the CDR and SRM categories

Given the range of geoengineering proposals presented to participants, it is unsurprising that people differentiated between technologies, and particularly between the two categories of geoengineering which are rooted in such different philosophies. In general, CDR approaches were more popular than SRM approaches, and these findings are supported by initial survey work (Spence et al, 2010). As part of a nationally representative UK survey of almost 1,800 people in early 2010, a number of questions about geoengineering were asked. Self-reported knowledge about geoengineering was found to positively predict, albeit weakly, CDR support – that is, the more people reported that they knew something of geoengineering in general, the more likely they were to support the use of CDR techniques. However, knowledge about geoengineering was a negative predictor of support for SRM – that is, the more people reported they knew, the less they supported the development of SRM techniques (see Pidgeon et al, in press, for more detail). An important task for future public engagement will be to investigate in more detail the reasons that people distinguish between CDR and SRM approaches – but the available evidence (deliberative and survey-based) suggests that CDR technologies are generally preferred.

3.3 The link between climate change mitigation and geoengineering

It is noteworthy that increased concern about climate change seemed to be linked to greater support for geoengineering. This is also supported by initial survey data – Pidgeon et al (in press) found that concern about climate change was positively correlated with support for geoengineering in general. A key conclusion from 'Experiment Earth?' was that most participants accepted the need for geoengineering on the basis that mitigation might not be effective enough. This relates directly to the concern expressed earlier in the paper that the 'Experiment Earth?' team may have placed too much emphasis on the notion of mitigation strategies being insufficient to deal with a climate 'catastrophe', although the report acknowledges this influence.

However, there is one other aspect of the way in which mitigation and geoengineering approaches were described that raises important questions about the way in which the framing of the information may have influenced the results obtained. The 'Experiment Earth?' report states on Page 8 that:

> "It is proving difficult to establish global political action on tackling climate change" (Page 8, Ipsos MORI, 2010).

On Page 28, it is stated that participants were informed that mitigation on a large scale will require political will. Although accurate, the notion that this is a 'disadvantage' of mitigation strongly implies that political will is not a barrier to geoengineering approaches (c.f. Gardiner, 2011). In fact, the entire 'Plan B' narrative that features so strongly in broader discussions of geoengineering is predicated on the assumption that geoengineering is somehow more straightforward than mitigation or adaptation – something that should be tried if the other approaches fail.

While it is possible that geoengineering technologies could be pursued independently of governance schemes, most commentators have advocated international regulation as a prerequisite for (at least some) geoengineering technologies (see, e.g., Royal Society, 2009; Rayner et al, 2010). This means that deployment and even large-scale research on geoengineering is likely to require significant political will, and public support, in exactly the same way as any other policy option would do. For some, the notion of climatic engineering is less problematic than what could be construed as 'social engineering' through behavioural changes, but this is a personal judgment. Although the 'Plan B' narrative was not dominant in Experiment Earth, the implication of identifying political will as a 'disadvantage' of mitigation approaches is that this would not be as much of a barrier for geoengineering.

3.4 Naturalness

The report concluded that perceived naturalness was a key theme that underpinned many of the principles participants articulated for assessing geoengineering proposals, and claimed that:

> "Across the dialogue events, processes were seen more positively when they were thought to be natural" (P32, Ipsos MORI, 2010).

One of the recommendations contained in the 'Experiment Earth?' report for research funders and decision makers (see Table 4) was to consider participants' concerns about perceived 'naturalness' of different geoengineering technologies. As perceived naturalness was such an important underlying theme, it is critical to understand how this issue was dealt with by the research team, in terms of the language and imagery used to convey different aspects of geoengineering technologies.

Based on longstanding work documenting the qualitative factors influencing the public perception of risk (Slovic, 2000), Pidgeon et al (in press) argued that one important factor in determining public attitudes towards geoengineering technologies would be the extent to which they were perceived as 'natural'. Pidgeon et al suggested that:

> "It is not at all difficult to see how some of the current proposals for geoengineering (e.g. iron fertilisation, sulphate aerosols) might indeed have several of the qualitative risk characteristics which make technologies less acceptable to people, something which may also help to explain their current sensitivity amongst a number of external commentators and environmental groups" (Pidgeon et al, in press, p9).

One of the central conclusions from the 'Experiment Earth?' report was that perceived naturalness did indeed play an important role in determining public attitudes. Some of the technologies discussed (e.g. afforestaion and biochar) genuinely do involve scaling up 'natural' processes, and unsurprisingly, these techniques were seen by participants as most strongly embodying the notion of naturalness. The challenge for facilitators with these technologies was to accurately convey the scaling-up that would be required in order for them to be effective – a concern noted by the 'Experiment Earth?' team in their own report.

However, it seems likely that the some of the technologies identified as being 'natural' were (unintentionally or otherwise) presented in this way by the research team and experts at the deliberative events. The analogies used to describe certain technologies alluded very strongly to a 'naturalness', while others did not. For example, chemical vents for capturing carbon dioxide from the air were repeatedly described as 'artificial trees', while the release of sulphur particles into the stratosphere was reported to participants as being 'no different to a volcano'. While these characterisations might be technically accurate, they also provide a powerful framing: that the way to think about these technologies is by analogy to existing 'natural' processes.

Leaving aside any discussion of what constitutes a 'natural' process, participants presented with technologies that are 'like trees' or 'similar to volcanoes' are being provided with a strong interpretive frame.[6] The fact that participants in 'Experiment Earth?' were concerned with naturalness is not surprising – well-established risk research from a number of different technological domains suggests that this is an important factor for determining risk judgments (Slovic, 2000). But presenting some technologies using a direct analogy to natural processes is likely to have influenced which technologies were perceived in this way. For example, one participant in Event 3 summarising a small group discussion from earlier in the day stated that:

> "I had concerns that sulphate particles were not very natural…but the scientists explained to us that obviously they were natural, and with the association with the volcano recently, they explained it was the same sort of thing and that there were particles even in this room" (Female participant in Event 3).

Finally, public concerns about naturalness were described in general by the 'Experiment Earth?' report as reflecting a version of the 'trolley problem' – the well known ethical dilemma that shows people differentiate between intentional and unintentional acts. But while notions of intention are likely to play a role in

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[6] At the time that the public dialogue was taking place, the Eyjafjallajokull volcano was erupting in Iceland, causing severe disruption to aviation across Northern Europe. It could be argued, therefore, that drawing an analogy with a volcano would have been more likely to act as a negative reference point for participants evaluating sulphate aerosol technologies. However, the finding from 'Experiment Earth?' that processes were perceived more positively the more they were seen to be natural suggests that 'naturalnesss' framings should be treated with caution (whichever direction they are likely to bias participants' responses).

determining whether something is perceived as natural or not, it is also possible that participant interest in naturalness is a deeper expression of concern about the continuation of the industrial project that is now know to have had a significantly negative impact on the 'natural' environment. Participants' concerns about naturalness may in fact be reflecting a deeper question about whether geoengineering is sustainable (in the broadest sense).

4. Recommendations for future public engagement on geoengineering

4.1 *Recommendations from 'Experiment Earth?'*

'Experiment Earth?' concluded with a set of nine recommendations (summarised in Table 4).

Recommendations from this study for NERC and other research funders and decision makers are to:			
1. Take account of the results of this study when discussing geoengineering priorities in future. In particular, recognise that information about the public's opinions and understanding of a subject can complement and support information from scientists and policymakers in the decision-making process.	2. Ensure future plans for geoengineering research and deployment take place in the context of the continuing need for mitigation, considering the moral hazard and opportunity costs faced in research decisions.	3. Consider participants' concerns around perceived '*naturalness*' in discussions about future geoengineering research and deployment.	4. Take account of participants' specific concerns that geoengineering research and Deployment should be assessed in terms of controllability; reversibility; effectiveness in terms of costs and benefits; timeliness; and potential for fair regulation.
Recommendations for future public engagement on geoengineering research:			
5. Continue to engage the public with geoengineering research, as requested by participants in this dialogue. Dialogue should be an on-going process, as public opinion is dependent on context and will change over time. Dialogue may also be required at different stages of research and deployment, to engage the public on specific issues relating to different technologies.	6. Keep the public informed about the efficacy, costs and side effects of any technologies that are researched, as research progresses and as such information becomes available. This helps the public to stay involved in the decision-making process, and ensures that their views are based on the most up to date information.	7. Further dialogue activity should include people from the developing world, and scientists from all over the world.	

Recommendation for communicating climate science:	
8. Future science communication activities on climate change, including any future geoengineering dialogue, should take account of the 'Communicating Climate Science' findings in this report. These include: public awareness of climate science and the scale of climate systems, communicating uncertainty, trust in science, awareness of how science is done, and differences between the 'scientific' view and the public view of issues.	9. There is also a need for further dialogue on the subject of 'naturalness' to establish what this term means to the public (see recommendation 3, above) and explore public attitudes to, and scientific understanding of, the role of humans in natural systems and interactions between humans and the environment.

Table 4: 'Experiment Earth?' recommendations.

It is our view that these are valuable and appropriate recommendations. The recommendations that follow are derived from our preceding analyses of the context, method, framing and results of 'Experiment Earth?'. They are not intended to replace or challenge the recommendations of 'Experiment Earth?', but rather to provide additional guidance for future public engagement on geoengineering.

4.2 Aim for less complexity in the presentation of the science

It is neither possible nor desirable to eliminate technical language from discussions of geoengineering. However – and especially considering participants' concerns about the difficulty of some of the material presented – it is important to provide only as much technical information as people are comfortable with. This will obviously vary according to the particular audience, but assuming that participants in public deliberations represent a range of educational and socio-economic backgrounds, every attempt should be made to make the materials as straightforward as possible. This could be achieved in a number of ways, including removing or simplifying graphs and technical figures (which are unfamiliar to those without a science background) and presenting fewer examples of geoengineering technologies. While presenting fewer technologies would inevitably limit the range of information available to participants, it might also help to avoid the technologies being seen as a list of ranked preferences (obscuring more general discussions about the concept of geoengineering).

4.3 Go beyond framing geoengineering as a set of technologies

In many respects there is no single thing called geoengineering and accordingly (as has also been argued in the case of nanotechnologies – see Rogers-Hayden and Pidgeon, 2007), it makes better sense to signal this heterogeneity by referring to ‘geoengineering proposals’ as a plurality of approaches. But beyond this acknowledgment of the plurality of geoengineering technologies lies a deeper issue: geoengineering is much more than just a set of technologies. As Felt and Fochler (2010) have argued, there is a danger that participatory public engagement is still implicitly undertaken as a means to avoid societal dissent, "…educating and pacifying unruly publics resistant to top-down information" (Felt & Fochler, 2010, p221).

The evidence presented in ‘Experiment Earth?’ (and beginning to be documented elsewhere – see Pidgeon et al, in press) suggests that different instantiations of geoengineering will produce very different responses from members of the public. Inevitably, some will be preferred to others. But it is crucial at this very early phase in the development of geoengineering research that great care is taken to allocate appropriate significance to the social and ethical questions that these technologies raise. An important precedent in this regard are nanotechnologies – in deliberative work discussing nanotechnology with members of the public in both the UK and USA its energy applications were seen as relatively unproblematic compared to health and human enhancement issues, with the latter felt to raise particular ethical and societal questions (Pidgeon et al, 2008). Such different attitudes and responses across application domains of the same underlying technology can be explained using theoretical concepts from work on public perceptions of technological risk, where factors over and above probability and severity of harm are known to differentiate the acceptability of proposals. People may be intrigued by the prospect of a nanotechnology-enhanced tennis racket, but concerned by the notion of engineering novel particles at the atomic scale. Similarly, the notion of an ‘artificial tree’ that can absorb carbon dioxide may be popular, but the assumption that necessitates its use – that we have failed to mitigate climate change and therefore have had to resort to putting excess carbon underground – may make people feel uneasy.

For example, on page 25 of the ‘Experiment Earth?’ report, one participant from the Cornwall event is quoted as asking:

> "If we are capturing CO_2, are we not just capturing something that will need letting out in future?" (Participant from Cornwall event, p25, Ipsos MORI, 2010)

From a scientific perspective, it is easy to dismiss such seemingly simplistic logic. However, whether or not CO_2 is likely to leak out of the ground is only part of what this statement is about. The notion of storing up problems for the future, of failing to address the root cause of a problem, is a concept familiar from many moral and political discussions – government debt and spending is a pertinent current example. The underlying principle – that a problem should be dealt with now, and not swept under the carpet (or pumped underground) for later on, is a fundamental one (reflected in the strong preference among 'Experiment Earth?' participants for geoengineering not to distract from mitigation efforts).

Presenting geoengineering as a technology, or even a set of technologies, before permitting adequate time for reflecting on the underlying principles of geoengineering as a type of response to climate change is likely to fundamentally alter the public's views of it. Future public engagement exercises should take care to ensure that a discussion of technical pros and cons is preceded by an opportunity for social and ethical concerns to be deliberated. This will ensure that geoengineering is framed as more than simply a set of technologies.

4.4 Think carefully about framing – *'climate catastrophes', 'artificial trees' and 'Plan B'*

While it is possible that large-scale technologies might be deployed in response to a sudden or unexpected change in the global climate, there is no consensus among climate scientists of what would constitute a climatic 'emergency'. In fact, environmental organisations and commentators have been repeatedly criticised for placing undue emphasis on apocalyptic visions of 'climate catastrophes' or sudden, irreversible changes in the climate system (see, e.g., Hulme, 2009). While abrupt, non-linear climatic changes become increasingly likely as global temperatures increase (Schneider, 2004), it does not necessarily follow that we will be able to identify or respond to them using large-scale technologies such as geoengineering. Interestingly, participants in 'Experiment Earth?' identified a need for the government to define what is meant by a climate emergency, so that it would be clearer when geoengineering would be 'needed' (p41).

One of the methodological challenges of upstream engagement is to provide sufficient information to participants (so that they can form a view) but without overly constraining or biasing the information or contextual background frames used (Stirling, 2008). With regard to geoengineering, the way the climate change issue is developed, the range and detail of technologies described, and whether geoengineering is presented within a narrative of climate catastrophe or alternatively as merely one of a range of potential response options, would all be likely to affect responses. To the extent that geoengineering is being framed (intentionally or unintentionally) as a method of responding to a 'planetary emergency', then its legitimacy is likely to be increased. Future public engagement work should use the 'climate catastrophe' narrative with caution – firstly because there is a genuine question about whether a climatic 'emergency' could in fact be easily defined (Hulme, 2009), and secondly because it is a powerful framing.

Future research should also be cautious in describing particular geoengineering technologies as 'natural', or using direct analogies with natural processes such as the absorption of carbon dioxide by trees. Given the importance that participants attributed to the naturalness of the different technologies described, there is a need to ensure that technologies are not associated with the positive notion of 'naturalness' by analogy if, in fact, they are highly artificial. While it may be technically appropriate to describe air capture units as 'artificial trees', the analogy is likely to have resonance beyond its intended technical meaning – acting to reassure people that the technology is familiar, tried-and-tested, or environmentally benign. In any case, the idea that there is a clean distinction between 'nature' and other aspects of human societies is widely disputed (see, e.g., Macnaghten & Urry, 1998) suggesting that any appeal to naturalness as a feature of a geoengineering technology is likely to be problematic.

Finally, careful thought should be given to the way in which the link between political will and geoengineering is developed. Although geoengineering technologies were never explicitly described in 'Experiment Earth?' as more politically straightforward to initiate than mitigation strategies, the implication of describing existing strategies as politically difficult to implement is that geoengineering will be less so. But any responsible attempt to use geoengineering technologies will require the investment of significant political capital. Caution should be exercised, therefore, in presenting geoengineering technologies as potentially less politically problematic than mitigation. It may be that this is true – but at present there is no way of making that judgment, and in any case, individuals are likely to have different views.

4.5 Be mindful of unintended impacts of visual imagery and language

Because so many putative geoengineering technologies have not yet been developed to a stage where accurate visual impressions of them can be provided, using images of geoengineering poses a challenge for public engagement research. Images are certainly valuable explanatory tools – but they can also be misleading. At a minimum, visual images should be clearly labelled as 'artists' impressions' if they depict a technology that does not yet exist. But even clearly labelled images should attempt to present the technologies in as neutral a way as possible. There is a danger that visual images will convey unintended information to participants – and the same risk applies to descriptions of the (potential) risks and benefits of geoengineering technologies. CDR techniques may address the root 'cause' of climate change in the sense that they tackle levels of CO2, rather than treat the symptoms of its accumulation in the atmosphere (like SRM approaches). But what has caused such high levels of atmospheric CO2 in the first place? CDR technologies do not prevent fossil fuels from being burnt – and so they tackle the 'cause' of climate change in only a narrow sense of the word. Being cautious with descriptions and visual depictions of these as-yet-undeveloped technologies is imperative, and one way of circumnavigating potential problems is to pre-test images and language for perceived associations.

5 Conclusion

The 'Experiment Earth?' project was the first systematic attempt at upstream public engagement on geoengineering in the UK. The purpose of the current paper was to reflect on the framing, process, methods and findings of the ‘Experiment Earth?’ project, and offer a set of recommendations for future public engagement on this topic. In many ways, ‘Experiment Earth?’ should be considered a success – methodologically and in terms of the level of engagement achieved with participants (this is also the conclusion reached in the official evaluation report of the project – Collingwood Environmental Planning Limited, 2011). It seems clear that participants, researchers and funders learnt valuable lessons from the process, and it has provided a valuable platform on which to explore the issues around geoengineering in more depth in subsequent public engagement initiatives.

However, we also identified a number of issues that should be addressed in subsequent public engagement research – in terms of the information provided to participants, the way in which it was framed, the structure of the deliberation process and the use of particular terminology or imagery. The challenge of developing a methodologically sound format for upstream public engagement is an ongoing and reciprocal process. Practical experience in the field gives invaluable guidance about ‘what works’, while theoretical insights and opportunities for reflection allow practical procedures to be refined.

In subsequent work planned by the Cardiff University Understanding Risk Group, we seek to investigate in much greater depth the complex issues around framing, language and imagery that we have touched on in this working paper. Using both participatory methods of engagement (similar to those employed in ‘Experiment Earth?’) and more experimental, quantitative approaches (trialling and measuring the impact of different framings and portrayals of geoengineering technologies), we hope to answer some of the questions we have raised here. But identifying these pertinent avenues of investigation would not have been possible without the case study of ‘Experiment Earth?’ to learn from.

Over the coming decades, the possibility of developing and deploying geoengineering technologies will be defined by the decisions that societies have made about how to respond to climate change. Sufficiently radical mitigation and adaptation measures may negate the need for geoengineering. Inadequate attempts to reduce emissions of CO2 may make some form of geoengineering all but inevitable if we wish to avoid the predicted effects of ‘dangerous’ climate change. Or, geoengineering may remain such a daunting prospect that even the effects of dangerous climate change are deemed less risky than the possible unintended consequences of geoengineering the climate. The window of opportunity for making these societal decision is rapidly closing – but it is not yet shut. This means that there is a critical role for upstream public engagement to play in allowing at least some members of the public – outside of the political and democratic elites – to contribute to the conversation about whether or not to conduct ‘Experiment Earth’.

6 References

ACIA (2004). Impacts of a warming climate - Arctic climate impact assessment**.** Cambridge**:** Cambridge University Press.

Anderson, K. and Bows, A. (2008) Reframing the climate change challenge in light of post-2000 emission trends. Philosophical Transactions for the Royal Society A, 366, 3863-3882.

Anderson, K. and Bows, A. (2011) Beyond 'dangerous' climate change: emission scenarios for a new world. Philosophical Transactions for the Royal Society A, 369, 20-44.

Bauer, M. and Gaskell, G. (2002) Biotechnology: The Making of a Global Controversy. Cambridge: CUP.

Budescu, D. V., Broomell, S., & Por, H. (2009). Improving communication of uncertainty in the reports of the intergovernmental panel on climate change. Psychological Science 20, 299-308.

Collingwood Environmental Planning Limited. (2011). *Evaluation of 'Experiment Earth?' Public Dialogue on Geoengineering.* London, UK: Collingwood Environmental Planning.

Corner, A. and Pidgeon. N.F. (2010) Geoengineering the climate: the social and ethical implications. Environment: Science and Policy for Sustainable Development, 52(1), 24-37.

Dessai, S., Adger, W., Hulme, M., Turnpenny, J., Köhler, J. and Warren, R. (2004) Defining and experiencing dangerous climate change. Climate Change, 64(1-2), 11-25.

Felt, U., Fochler, M. (2010) Machineries for making publics: Inscribing and describing publics in public engagement, Minerva, 48, 219-238.

Gardiner, S.M. (2011). Some early ethics of geoengineering the climate: A commentary on the values of the Royal Society report. Environmental Values 20, 163-188.

Hagendijk, R. & Irwin, A. (2006). Public Deliberation and Governance: Engaging with Science and Technology in Contemporary Europe. Minerva 44, 167-184.

Hulme. M. (2009). Why we disagree about climate change: Understanding controversy, inaction and opportunity. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2007). A Report of Working Group I of the Intergovernmental Panel on Climate Change: Summary for policymakers. Retrieved April 2010 from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

Ipsos-MORI (2010) Experiment Earth? Report on a Public Dialogue on Geoengineering. Swindon: Natural Environment Research Council. Available from www.nerc.ac.uk/about/consult/geoengineering-dialogue-final-report.pdf

Irwin, A. and B. Wynne (eds) (1996) Misunderstanding Science? The Public Reconstruction of Science and Technology. Cambridge: Cambridge University Press.

Lorenzoni, I., Pidgeon, N.F. & O'Connor, R.E. (2005). Dangerous climate change: The role for risk research. Risk Analysis 25(6) 1287-1398

Macnaghten, P. & Urry, J. (1998). Contested Natures. London, UK: Sage Publications.

Oppenheimer, M. (2005). Defining dangerous anthropogenic interference: The role of science, the limits of science. Risk Analysis 25 (6) 1399 – 1407.

Pidgeon, N., Corner, A., Parkhill, K., Spence, A. & Butler, C. (in press). Public Perceptions of Geoengineering - Knowledge, Risk and Acceptability. Manuscript under submission to Philosophical Transactions of the Royal Society (A).

Pidgeon, N.F., Harthorn, B., Bryant, K. and Rogers-Hayden, T. (2008) Deliberating the risks of nanotechnology for energy and health applications in the US and UK. Nature Nanotechnology, 4, 95-98.

Pollack, H. N. (2005). Uncertain science . . . uncertain world. Cambridge, United Kingdom: Cambridge University Press.

Poortinga, W., Spence, A., Whitmarsh, L., Capstick, S. & Pidgeon, N. (2011). Uncertain climate: An investigation into public scepticism about anthropogenic climate change. Global Environmental Change 21, 1015-1024.

Rayner, S., Redgwell, C., Sauvulescu, J., Pidgeon, N. and Kruger, T. (2010) Draft principles for the conduct of geoengineering research (the 'Oxford Principles'). Reproduced in House of Commons Science and Technology Committee, The Regulation of Geoengineering, Fifth Report of the session 2009-2010, HC221, 18th March 2010.

Renn, O., Webler, T. & Wiedemann, P. (Eds). (1995). Fairness and Competence in Citizen Participation: Evaluating Models for Environmental Discourse. Kluwer Academic Publishers: Dordrecht, The Netherlands.

Rogers-Hayden, T. and Pidgeon, N.F. (2007) Moving engagement "upstream"? nanotechnologies and the Royal Society and Royal Academy of Engineering inquiry. Public Understanding of Science, 16, 346-364.

Rosa, E.A. and Clark, D.L. (1999) Historical routes to technological gridlock: nuclear technology as prototypical vehicle. Research in Social Problems and Public Policy, 7, 21-57.

Royal Society (2009) Geoengineering the Climate: Science, Governance and Uncertainty. Science Policy Centre Report 10/09. London; The Royal Society.

Royal Society. (2010). Climate change: A summary of the science. http://royalsociety.org/climate-change-summary-of-science/

Schneider, S. (2004). Abrupt non-linear climate change, irreversibility and surprise. Global Environmental Change 14, 245–258.

Slovic, P. (2000) The Perception of Risk. London: Earthscan.

Stirling, A. (2008) Opening up and closing down: power, participation and pluralism in the social appraisal of technology. Science, Technology and Human Values, 33, 262-294.

Spence, A., Venables, D., Pidgeon, N., Poortinga, W. and Demski, C., (2010). Public Perceptions of Climate Change and Energy Futures in Britain: Summary Findings of a Survey Conducted in January-March 2010. Technical Report (Understanding Risk Working Paper 10-01). Cardiff: School of Psychology.

Sturgis, P. and Allum, N. (2004) Science in society: re-evaluating the deficit model of public attitudes. Public Understanding of Science, 13, 55-74.

Wilsdon, J. and Willis, R. (2004) See-Through Science**:** Why Public Engagement Needs to Move Upstream. London: Demos.

Wynne, B. (2007) Public participation in science and technology: Performing and obscuring a political-conceptual category mistake, East Asian Science, Technology, and Society: An International Journal, 1(1), 1–13.