Safety First! Framing and Governing Climate Geoengineering Experimentation

Rob Bellamy

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Abstract

Experiments for technology proposals to deliberately intervene in the Earth's climate system to moderate anthropogenic climate change, collectively known as geoengineering, have begun. Recent controversies have demonstrated that they are more than simply a technical concern: they are political, social and ethical ones too. With more experiments planned, it is imperative that the ways in which such ambitions are understood and used by different participants in discourses on geoengineering are scrutinised by social science. For the first time, this article examines framings of geoengineering experimentation using a corpus approach to thematic discourse analysis. The analysis identifies eleven distinct framings with twenty–four distinct sub–frames under four thematic constructs: knowledge, precaution, control and society. These framings are discussed in the light of research into divergent epistemic and institutional cultures. The article concludes by offering a 'clumsy' solution space for geoengineering governance and climate response governance at large.

Introduction

experiment /ɪkˈspɛrɪm(ə)nt/ *n* **1** a scientific procedure undertaken to make a discovery, test a hypothesis, or demonstrate a known fact. **1.1** a course of action tentatively adopted without being sure of the outcome. *v* **1** perform a scientific procedure, especially in a laboratory, to determine something. **1.1** try out new ideas or methods *(Oxford English Dictionary)*.

In July 2012 one hundred tonnes of iron sulphate was released into the North Pacific Ocean off the western seaboard of Canada (Tollefson, 2012). Those behind the release, the Haida Salmon Restoration Corporation, had done so in an attempt to stimulate the growth of phytoplankton. The reasons for this were twofold: first, to increase the declining local salmon population in support of fishing efforts from the Haida Gwaii archipelago; and second, to sequester atmospheric carbon dioxide in order to sell carbon credits to companies seeking to offset their greenhouse gas emissions. This experiment in 'ocean iron fertilisation' was the latest in a string of such experiments testing the 'iron hypothesis' of carbon drawdown (Martin, 1990). Yet, it sparked controversy later that year when British newspaper *The Guardian* reported the 'rogue' incident as being in violation of two United Nations conventions (Lukacs, 2012). The furore was in large part due to the experiment's conceptual intention: testing climate 'geoengineering'.

Notwithstanding the long and chequered history of its antecedents (Fleming, 2010), the idea of deliberate, large–scale intervention in the Earth's climate system has recently gained prominence as a possible response to anthropogenic climate change (Royal Society, 2009). Insufficient efforts to mitigate climate change through reductions in greenhouse gas emissions and the risk of a climate 'emergency' are two dominant problem definitions driving interest in 'geoengineering' technology (Bellamy *et al.*, 2012). Such concerns are used to justify geoengineering research, and increasingly, experimentation (Royal Society, 2009; Novim, 2009). Geoengineering is not only limited to ocean iron fertilisation but subsumes a disparate array of technology proposals. These proposals can be broadly divided amongst those that seek to capture and sequester carbon dioxide from the atmosphere ('carbon geoengineering'); and those that seek to reflect a proportion of sunlight away from the Earth ('solar geoengineering').

Most geoengineering proposals have so far undergone no experimentation beyond that in laboratories or through computational modelling. The most notable exception to this has been the inadvertent field experiments in ocean iron fertilisation carbon geoengineering that took place prior to the Haida Gwaii incident (Strong *et al.*, 2009); of which there have been fourteen, including SOIREE (Boyd & Abraham, 2001) and LOHAFEX (Thiele *et al.*, 2012). Yet, solar geoengineering experiments in enhancing the reflectivity of clouds at sea ('marine cloud brightening') and in injecting reflective sulphuric acid aerosol into the stratosphere ('stratospheric aerosol injection') have also begun. Much as with prior experiments in ocean iron fertilisation, those in marine cloud brightening have so far been inadvertent; that is to say, they were conducted to explore basic questions in our scientific understanding of Earth systems. For instance, whilst the Eastern Pacific Emitted Aerosol Cloud Experiment (E–PEACE), sought to address gaps in our knowledge of cloud perturbation processes (Russell *et al.*, 2013), it has also shed light on the capacity for marine cloud brightening to produce cooling effects (Russell, 2012).

Experiments in stratospheric aerosol injection have been more purposeful. This is in no small part due to its increasingly hegemonic place in the field of geoengineering (Bellamy *et al.*, 2012). Despite assessment findings to the contrary (Bellamy *et al.*, 2013; Bellamy *et al.*, in press), the proposal is peddled for its alleged effectiveness (Lenton & Vaughan, 2009), feasibility (Fox & Chapman, 2011), and low costs (Barrett, 2008). To test this technology, scientists and engineers have turned to observe the behaviour of aerosols released by volcanoes in 'natural' experiments (Robock *et al.*, 2013) and by releasing aerosols from helicopters (Izrael *et* *al.*, 2009). A somewhat more ill–fated experiment attracted controversy after seeking to test delivery hardware as part of the Stratospheric Particle Injection for Climate Engineering (SPICE) project (Cressey, 2012). Had it not been indefinitely postponed due to an absence of governance and a conflict of interest in technology patenting, the test–bed would have seen the injection of water to a tropospheric height of 1km via a pipe and tethered balloon.

The level of intervention in the environment demanded by experimentation differs significantly between geoengineering proposals. Of course, experimentation with some less invasive proposals, such as direct air capture and storage of carbon dioxide, 'can and should be encouraged without delay' (Royal Society, 2009: 52). Other proposals, however, such as those discussed above with international, transboundary or commons implications, demand a much higher level of technical intervention. Yet, through controversy, experimentation with these proposals has already demonstrated that it is more than simply a technical concern: it is a political, social and ethical one too. With more experiments planned (Latham *et al.*, 2012; Parson & Keith, 2013; Keith, 2013) it is vital that the ways in which such ambitions are understood and used by different participants in discourses on geoengineering are scrutinised by social science. Such research will play an important role in developing principles for geoengineering governance (Rayner *et al.*, 2013) and in supporting responsible research and innovation (Owen *et al.*, 2013).

A number of scholars have already begun to examine understandings and uses of 'geoengineering' more broadly both in the media and in academic and grey literature. Through discourse analyses of the ways in which social actors have chosen to organise and communicate, or 'frame' (Entman, 1993), geoengineering, social scientific research has revealed a variety of framings. In the media it was initially framed supportively, through 'spectacle' for its possible role as a solution to climate change (Buck, 2012), or as a remedy for climate change 'catastrophe' through three master metaphors: 'the planet is a body', 'the planet is a machine', and 'the planet is a patient or addict' (Nerlich & Jaspal, 2013). Media framings have since diversified, utilising frames on risk, governance and accountability, economics, morality, security and justice (Porter & Hulme, 2013); and war, controllability and health, in both support and opposition of geoengineering (Luokkanen *et al.*, 2013). Further diversification since is argued to have opened up the societal debate on geoengineering through framings of ambivalence, avoiding catastrophe, pragmatism, norms and values, benefits for society, controversy, a techno–fix and of governance (Scholte *et al.*, 2013).

Discourse analyses of academic and grey literature on geoengineering inherently contend with more substantive and detailed data sets than those of media publications. Yet, framings in the geoengineering assessment literature have been revealed to be less diverse, 'closing down' on particular problem definitions, knowledges and pathways (Bellamy *et al.*, 2012). Discursive strategies in 'philosophical exceptionalism' and 'market and the economy' amongst scientific and political advocates of geoengineering have shown similar scope for closure (Sikka, 2012). The broader academic literature on geoengineering has been shown to hold somewhat more varied framings with emphases on 'risk–benefit', 'governance' and 'natural balance' (Huttunen & Hildén, 2013). High–profile academic and grey literature reports have shown yet further variation in framings of the geoengineering imaginary, and in particular revealing tensions between them: 'science before policy, or vice versa'; 'geoengineering is new, or old'; 'balancing the Earth system, or societal reform'; and 'geoengineering research (or deployment) now, or geoengineering is a distraction from mitigation' (Markusson, 2013).

Building on this earlier research into geoengineering discourses more generally, for the first time this article seeks to explore the more specific understandings and uses of geoengineering *experimentation* and related concepts by different participants in the discourse. It begins by detailing the research methodology before reporting and then discussing its analytical findings. The article concludes by summarising its contribution to the literature and drawing recommendations for future research and policy.

Method

A structured set of texts, or corpus approach (Stubbs, 2004) to discourse analysis was used here to explore how different participants in geoengineering discourses understand and use 'experimentation' and related concepts. In this paper I focus on high–profile academic and grey literatures on geoengineering to construct a specialist corpus (Hunston, 2002) of substantive and detailed publications. I used a range of selection criteria to ensure the capture of understandings and uses by diverse perspectives. In addition to satisfying a need for utility with respect to the research question (McCarthy & Carter, 2001), i.e. an attention to 'experimentation', my selection criteria sought to ensure corpus sample authenticity, representativeness and validity (Biber, 1994; Kennedy, 1998; Reppen & Simpson, 2002). These criteria concerned the publications': (1) international and organisational context; (2) disciplinary focus; and (3) attitude towards geoengineering research. Twelve publications were selected to complete a corpus spanning five years of discourse (2009 – 2014) (Table 1).

Table 1 Publications selected for inclusion in the corpus

No.	Citation	Notes on selection†
1	The Royal Society (2009): Geoengineering the climate: science, governance and uncertainty. 98pp.	UK scientific fellowship; interdisciplinary; pro research.
2	Novim (2009): Climate engineering responses to climate emergencies. 66pp.	US scientific non–profit; natural and engineering science; pro research.

3	House of Commons Science and Technology Select Committee (2010): The regulation of geoengineering. *The Stationary Office: London*. 116pp.	UK Government select committee; pro research.
4	ETC Group (2010): Geopiracy: the case against geoengineering. 56pp.	International technology action group; contra research.
5	United States Government Accountability Office (2010): Climate engineering: technical status, future directions, and potential responses. 135pp.	US independent congressional evaluator; pro research.
6	German Federal Ministry of Education and Research (2011): Large–scale intentional interventions into the climate system? Assessing the climate engineering debate. 170pp.	Academic commission on behalf of the German Federal Ministry; social science; pro research.
7	Solar Radiation Management Governance Initiative (2011): Solar radiation management: the governance of research. 70pp.	International academic initiative; interdisciplinary; pro research.
8	Bipartisan Policy Centre's Task force on climate remediation research (2012): Geoengineering: a national strategic plan for research on the potential effectiveness, feasibility, and consequences of climate remediation technologies. 40pp.	US public policy non–profit; natural and engineering science; pro research.
9	Parson, E. and Keith, D. (2013): End the deadlock on governance of geoengineering research. *Science*, **339**, 1278 – 1279.	US academic policy forum; natural science; pro research.
10	Pidgeon, N., Parkhill, K., Corner, A. and Vaughan, N. (2013): Deliberating stratospheric aerosols for climate geoengineering and the SPICE project. *Nature Climate Change*, **3**, 451 – 457.	UK academic research article; social science; pro research.

11	Keith, D. (2013): A case for climate engineering. *MIT Press: Cambridge, MA*. 194pp.	Personal argument; interdisciplinary; pro research.
12	Hulme, M. (2014): Can science fix climate change? A case against climate engineering. *Polity: Cambridge*. 144pp.	Personal argument; interdisciplinary; contra research.

† Designated 'pro' or 'contra' attitudes towards geoengineering research are broadly representative for the purpose of corpus selection, but may not capture nuances present in the publications.

The Royal Society's (2009) report was the first of a number of high–profile publications on geoengineering that have recently emerged, establishing an authoritative interdisciplinary agenda for future research and experimentation. In concert, the Novim (2009) report outlined a decade–long agenda for technical experimentation with solar geoengineering. The UK House of Commons Science and Technology Select Committee (2010) later scrutinised geoengineering with a view to regulating experimentation in their report. The technology action group ETC (2010) concurrently published their report in a first vocal opposition to geoengineering experimentation. The US Government Accountability Office (US GAO, 2010) released its technology assessment also at that time to explore future directions for research and experimentation. The German Federal Ministry of Education and Research (FMER, 2011) later commissioned an argument map of support for and opposition against geoengineering research and experimentation in its report.

In the wake of concerns raised in the Royal Society's (2009) report, the Solar Radiation Management Governance Initiative (SRMGI, 2011) later explored the governance needs of solar geoengineering research and experimentation in its report. The following year, the Bipartisan Policy Centre (2012) set out a national strategic plan for technical geoengineering research and experimentation in its report. By 2013, frustration with an apparent lack of progress in solar geoengineering experimentation led advocates to outline near–term steps to progress in a policy forum article (Parson & Keith, 2013). Concurrently, a social scientific perspective on engaging members of the public with the SPICE project test–bed experiment was published (Pidgeon *et al.*, 2013). Advocacy of solar geoengineering experimentation has since continued to gain momentum, with outspoken advocate David Keith (2013) laying out a case for climate engineering experimentation in a short book. Meanwhile this case has been critiqued by geographer Mike Hulme (2014), who has argued strongly against geoengineering experimentation in an equally succinct book.

The selected corpus of publications holds a diversity of perspectives from UK, US, German and international organisational contexts across academia, civil society and government. Moreover, it attends to both supportive and oppositional attitudes towards geoengineering research through disciplinary lenses from across the natural, engineering and social sciences. Of course, however, the number of publications in the corpus is limited, and so too is the static timeframe over which it extends (Hunston, 2002). Indeed, as Reppen & Simpson (2002: 97) recognise, 'no corpus can be everything to everyone', and as Stubbs (2004: 113) also recognises, any corpus 'is a compromise between the desirable and the feasible'. Nevertheless, it is not the purpose of this research to conduct an exhaustive analysis, but to be an exploratory one that pays due attention to diverse perspectives on geoengineering experimentation; and one that may form a basis for future analyses as the discourse inevitably evolves.

The diverse contextual, disciplinary and attitudinal perspectives contained not only between publications in the corpus, but particularly within them, inevitably reveal tensions where different framings are used in the same publication (cf. Markusson, 2013). Hence, I considered framings at the corpus, or thematic, level, rather than attempting reduce individual publications to singular framings. I performed the analysis using the influential method for thematic discourse analysis outlined by Braun & Clarke (2006) in which I followed five phases. First, I undertook close reading of the publications to ensure thorough familiarity with the data, and detailed notes were taken on understandings and uses of ‘experimentation’ throughout the corpus. Second, I inductively generated (Patton 1990) semantic codes (Boyatzis, 1998), that is to say, codes of explicit or surface meanings of the data, to reflect interesting features across the entire corpus in a systematic fashion. In doing so, I recognise the active role that researchers play in identifying themes and frames in such analyses, and do not view ‘inductive’ coding as passively ‘giving voice’ to participants in the discourse (Ely *et al.*, 1997; Fine, 2002). Third, I clustered codes into ‘sub–frames’, which were in turn clustered into larger patterns of ‘framings’, and overall ‘themes’; before fourth, ensuring that the themes and frames ‘worked’ in relation to coded extracts and the full data set. Finally, themes were subject to ongoing refining as the analysis developed.

Analysis

The initial analysis revealed eight primary ways through which publications in the corpus discourses technically understood, or by proxy defined, geoengineering ‘experimentation’. First and foremost, publications spoke of experiment *scale* and *locus*. Scale was often conveyed through vague terminologies such as ‘small’, ‘medium’ or ‘large’, or somewhat more specific terms including ‘subscale’, ‘regional’ and ‘system–wide’. Understandings of locus were implicitly linked to those of scale, ranging from ‘computational’ or ‘laboratory’ experiments; to ‘real–world’, ‘outdoor’ or ‘field’; to ‘transboundary’, ‘stratospheric’, ‘global’ or ‘outer space’. *Temporality* was also an important definitional tool, describing ‘early, ‘short’, ‘long’, or even ‘perpetual’ experimentation. As well as referring to potential tests for *specific* geoengineering proposals (predominantly stratospheric aerosol injection, ocean iron fertilisation and marine cloud brightening) or existing experiments (including the SPICE test–bed, the Haida Gwaii incident, and E–PEACE), publications also spoke of *intentionality*.

Besides 'deliberate' experimentation driven by human agency, 'inadvertent' or 'accidental' was used to refer to those experiments that had taken place under different purposes (such as E–PEACE), and 'natural' referred to observations of natural phenomena analogical to geoengineering (such as volcanic eruptions). *Utility* distinguished 'scientific' from 'commercial' experiments in 'business'. Lastly, r*isk* was used to demarcate 'non–invasive' and 'minimal impact' experiments from 'high risk' or potentially 'irreversible' ones.

Three publications in the corpus went further by promoting their understandings of experimentation through formal categorisations for solar geoengineering. The Novim (2009) and SRMGI (2011) reports and Keith's (2014) book outline three comparable 'levels' of experimentation (Table 2). These levels broadly comprise non–field experiments ('A'), field experiments ('B') and *de facto* experiments in deployment ('C'). Whilst the SRMGI report viewed these categories as discrete objects for governance, the Novim report and Keith's book saw them more as successive phases for experimentation. Principally concerned with definitional markers of technical risk, locus and scale, none of the categorisations drew on all of the parameters identified across the full corpus of publications.

Table 2 Levels of proposed categories for solar geoengineering experimentation

Level	Novim (2009)	SRMGI (2011)	Keith (2014)
A	1. Non–invasive laboratory, computational research and analogue case studies (*locus*, *intentionality, risk*)	1. Non–hazardous studies (*locus*, *risk*) 2. Laboratory studies or passive observations of nature (*locus*, *intentionality*, *risk*)	1. Theory and laboratory work (*locus*)
B	2. Field experiments (*scale*, *locus*, *temporality*, *risk*)	3. Small field trials (*scale*, *locus*, *temporality*, *risk*)	2. Experiments in the atmosphere (*scale*, *locus*, *risk*)

		4. Medium and large–scale field trials (*scale*, *locus*, *temporality*, *risk*)	
C	3. Monitored deployment (*scale*, *risk*) 4. Intervention maintenance (*temporality*) 5. Disengagement (*intentionality*, *risk*)	5. Deployment activities (*scale*, *locus*, *temporality*, *risk*)	3. Minimal deployment (*scale*, *risk*) 4. Gradual deployment (*scale*, *temporality*, *risk*)

Definitional markers used for each level are indicated in parentheses.

Such technically–defined understandings of experimentation are, however, confounded by diverse social understandings and uses of the concept. In–depth analysis uncovered eleven distinct framings with twenty–four distinct sub–frames of geoengineering experimentation under four thematic constructs across the corpus of publications: (1) knowledge, (2) precaution, (3) control and (4) society. The following sections of analysis introduce the **framings** and *sub–frames* within these four themes with reference to illustrative supporting quotations from the corpus' publications.

Knowledge

The first theme was concerned with the role that scientific knowledge should, or could, play in decision making on geoengineering experimentation. By far the most prevalent framing under this theme was that **'we need to know more'**. First and foremost, it contended that an apparent deficit in scientific knowledge justified different levels of experimentation to *gain understanding and reduce uncertainty*. Whilst it was stressed that experimentation should take place in tandem with social scientific research into the potential consequences of such activity, the purposes were technical in nature, seeking to determine geoengineering efficacy, feasibility and impacts:

> 'Research is urgently needed for evaluating which methods are feasible, and to identify potential risks. The principal R&D requirements in the short–term are for small / medium scale research (e.g. pilot experiments and field trials)' (Royal Society, 2009: 61).

> 'At some point… large–scale field tests will be needed to evaluate the effectiveness of [solar geoengineering] systems and to assess their potential impacts on regional and global climate and ecosystems' (BPC, 2012: 29).

The gains in scientific knowledge might not be restricted to geoengineering; it could also 'benefit our understanding in [engineering, climate science and climate monitoring]' (Novim, 2009: 42). Knowing more about geoengineering from experimentation could also be used to *inform governance*:

> 'There are many possible field experiments with negligible associated risk that would be useful for finding out more… to inform future decisions' (SRMGI, 2011: 50).

> 'Outdoor experiments will, I anticipate, provide a better platform than mere theory on which to anchor debates about governance of geoengineering' (Keith, 2013: 84).

For ambitions to *test technology designs* for geoengineering, experimentation has no substitute. This imperative sought to overcome 'no experimental demonstration of proof of concept' (US GAO, 2010: 16) in a number of geoengineering proposals, such as stratospheric aerosol injection:

> 'Low–magnitude, short–term field experiments will likely be sufficient to validate aerosol deployment systems, and to observe the temporal and spatial distribution of various aerosol materials in the stratosphere' (Novim, 2009: 38).

Yet, whilst smaller and ostensibly lower risk experiments have been endorsed in the short term, their limitations, and those of successive levels of experimentation, have been used to *justify further experimentation*, culminating in a rationalisation for global experimentation:

> '[Non–invasive] research could dramatically reduce current uncertainty, but fully addressing each the (sic) relevant questions will minimally require low–level field experiments that have some potential for detectable impact on the climate system' (Novim, 2009: 33)... 'However there are important limits to what such subscale experiments could conclusively demonstrate... Natural variability... place[s] fundamental limits on what could be determined from any short–term and/or low–level stratospheric aerosol deployment experiments' (*ibid*: 42)... 'Any conclusive field–test will require a non–trivial stratospheric aerosol loading to be maintained for several years; [and] a global trial would become conclusive in a shorter duration than any regional experiment' (*ibid*: 43).

Amidst prevailing calls for more research, other, less visible perspectives maintained that **'we already know enough'** to *rule out further experimentation*. Under this framing, certain geoengineering proposals, principally ocean iron fertilisation, were deemed to be a lost cause. Citing findings of the Royal Society and the Intergovernmental Panel on Climate Change, it was argued that despite 'at least 13 experiments… the science of iron fertilisation is increasingly discredited' (ETC Group, 2010: 24). Other perspectives argued that **'we can't know'** from experiments because *experimentation is deployment* and is therefore completely unpredictable:

> 'Absurdly, the experiment with stratospheric aerosol injection would have to be justified on the (false) grounds that the outcome is already known, that it will deliver the desired 'beneficial' outcome, that a global thermostat *can* stabilise the climate. On the contrary. To embark on this course of action would indeed be to conduct a giant experiment, to take a leap in the dark. It is not possible to know what the consequences of such engineering would be' (Hulme, 2014: 111).

This framing represents a reaction to justifications for global experimentation with stratospheric aerosol injection and the idea that 'small–scale geoengineering is an oxymoron' (ETC Group, 2010: 37), or at least a 'slippery slope' from research to deployment (Parson & Keith, 2013: 1278).

Precaution

The second theme was concerned with perceptions of the risks posed by geoengineering experimentation and what measures, if any, should be taken in lieu of their possible impact. The most prevalent framing under this theme was **'safety first!'** which considered the risks of experimentation to be manageable subject to particular precautionary safety measures. Calls for 'carefully planned and executed experiments' (Royal Society, 2009: ix) were common amongst the corpus' publications, including with members of the public engaged as part of the SPICE project test–bed, which could only take place if 'the test–bed were safe for local inhabitants and the environment' (Pidgeon *et al.*, 2013: 454). The mainstay of precautionary measures under this framing came as appeals for *prior assessment*. Indeed, the former UK Chief Scientific Adviser giving evidence to the House of Commons Science and Technology Select Committee (2010) report was opposed to even small experiments taking place 'before the unintended consequences have been fully evaluated' (HoC STC, 2010: 37). With the exception of considering 'acceptability' (SRMGI, 2011; Pidgeon *et al.*, 2013), the nature of such prior assessments was to be wholly technical, concerning effectiveness, timeliness, impacts, reversibility, costs, funding and legality (Royal Society, 2009).

By technically differentiating between different levels of experimentation such as those recorded in Table 2, another precautionary measure would involve *prioritising safer experiments*. Such experiments were invariably viewed as small–scale:

> 'Small scale experiments that are not intended or expected to have noticeable climate or other large–scale impacts should come first' (BPC, 2012: 25).

> 'It is likely that early, safer research would have helped to better identify and characterise the risks that large experiments could pose' (SRMGI, 2011: 52).

Nevertheless, the inevitably higher levels of risk threatened by potentially larger experiments in the longer term led some to argue in favour of a pragmatic trade–off in *balancing safety with utility*:

> 'Experiments should be designed to strike an appropriate balance between two conflicting objectives: (a) minimising the possibility of negative climatic consequences...; and (b) maximising the utility of collected data for increasing understanding' (Novim, 2009: 25).

A somewhat less concerned attitude towards precaution came under the **'it's low risk'** framing. Here the risks of particular experiments could already be deemed negligible, requiring minimal or no precautionary measures. The 'miniscule' *small scale and familiar technology* to be used in planned experiments in stratospheric aerosol injection, for example, were considered safe and contrasted with allegedly 'exaggerated' opposing perspectives:

> 'Experiments that my collaborators and I are now contemplating would use less than a hundred kilograms of aerosol material – less than one ten–millionth of what we would need to add every year to make a readily measurable impact on climate. The experiments would be performed using the same scientific instruments and research platforms... that have been used for decades to study the causes of ozone loss in the stratosphere' (Keith, 2013: 82).

> 'One view, advanced by some nongovernmental organizations and a few scientists, invokes direct environmental risks (often exaggerated)... to seek strict control on a broad set of activities – for example, all geoengineering research, all field research, or all active environmental perturbation, no matter how small' (Parson & Keith, 2013: 1278)

With 'the potential to diminish some severe climate impacts' (Novim, 2009: 4), certain geoengineering experiments could also be considered *lower risk than climate change itself*, or an ambiguous climate 'emergency':

> 'We cannot accurately predict the results of our uncontrolled experiment on our planet, but it is certain that if we continue on our present course we are committing our children to climate changes that will be extraordinarily rapid' (Keith, 2013: 27).

Despite assertions that particular geoengineering experiments would be low risk, this perspective is in stark contrast with those that believe **'it's too risky'** at any level of such activity. Indeed, the potential impacts of 'even small–scale' (ETC Group, 2010: 24) experiments are considered too harmful; setting out on a path that could prove 'potentially devastating' (*ibid*: 39). Under this framing, the *risks are many, irreversible or unforeseeable* to an extent that they should preclude 'unleashing the experiment' (Hulme, 2014: 99):

> 'The potential for accidents, dangerous experiments, inadequate risk assessment, unexpected impacts, unilateralism, private profiteering, disruption of agriculture, inter–state conflict, illegitimate political goals and negative consequences for the global South is high' (HOME, quoted in Hulme, 2014: 92).

> '[It would] introduce unacceptable risk in large–scale climate engineering experiments that could permanently alter the chemistry of the atmosphere' (US GAO, 2010: 42)... [And through] coinciding with a natural volcanic eruption[s]... produc[e] unprecedented cooling' (*ibid*: 59).

Indeed, together with risks that could 'barely be imagined, let alone quantified' (Hulme, 2014: 92), these forewarnings are used to describe an approach for responding to climate change that 'flies in the face of precaution' (ETC Group, 2010: 3):

> 'A precautionary approach may apply where, for example, the impacts of geoengineering on the environment are not yet fully known but believed potentially to be serious, if not irreversible; the response to ocean fertilisation experiments under the [London Conven-

> tion] and [Convention on Biological Diversity]... is an example' (Royal Society, 2009: 38).

Under this framing, the precautionary principle itself can then be invoked so as to prohibit experimentation altogether.

Control

The third theme was concerned with the ways in which governance should exert control over geoengineering experiments. By far the most prevalent framing under this theme was that **'we need governance'**. Indeed, this unanimous verdict was echoed by members of the public engaged as part of the SPICE project test–bed, who contended that 'governance and regulatory structures should be under development now' (Pidgeon *et al.*, 2013: 455). Yet, beyond this universal call for governance, preferences for four quite different methods of control can be revealed. The first of these promotes *a global agreement* as the most appropriate course of action:

> 'Climate change is… a prime example of a global problem that requires a global solution. International regulation of climate engineering should therefore ideally… limit the side–effects of research as far as possible by establishing rules for the investigation of [geoengineering] technologies' (FMER, 2011: 106).

> 'An internationally agreed (but initially voluntary) code of conduct and system for approval for geoengineering research would be highly desirable… Only experiments with effects that would in aggregate exceed some agreed minimum (*de minimis*) level would need to be subject to such regulation' (Royal Society, 2009: 52).

Those experiments that fall beneath such an agreed minimum could be permitted to take place under conditions of 'hands–off' *self–regulation* by scientists, possibly in an 'allowed zone' (SRMGI, 2011: 49), and relatively free from the 'burdens' of regulation:

> 'Initial steps need not require the delay and inflexibility of enacting new laws or treaties but can come from informal consultation and coordinated decisions by research–funding and regulatory agencies of participating governments… [a] small–scale threshold would define a second boundary, below which participating governments agree that high–value research may proceed… Its level would reflect the fact that much promising process research has trivial environmental impact, smaller than common commercial activities—for example, average ΔRF ~10^{-6} Wm^{-2}. These are only 'geoengineering' research by virtue of their purpose, and imposing large regulatory burdens on them will merely create incentives to misstate their purpose' (Parson & Keith, 2013: 1279).

Indeed, one participant giving evidence to the UK House of Commons Science and Technology Select Committee (2010) report expressed their being in:

> 'Favour of fairly free research… we are in too large uncertainty still about many of these options to be able to even design the right regulations' (HoC STC, 2010: 78).

Both a global agreement regime and self–regulation could be adapted to support a 'flexible framework' for the governance of geoengineering experiments (SRMGI, 2011). However, for others, flexibility proffers too much scope for activity. Here, the governance that is needed is *a moratorium* on all experiments. Tightly coupled with the view that 'it's high risk' to conduct any level of experimentation, this might apply to 'geoengineering' broadly: 'A moratorium on real–world geoengineering experimentation is urgent' (ETC Group, 2010: 2); at a specific scale: 'Interventions above [a] large threshold would be subject to a moratorium' (Parson & Keith, 2013: 1279); or to specific geoengineering proposals, particularly stratospheric aerosol injection and ocean iron fertilisation:

> 'I am opposed to researching the aerosol injection technologies that might enable a thermostat for the planet' (Hulme, 2014: 137).

> 'In 2008, the [Convention on Biological Diversity (CBD)] was ahead of the curve when it adopted a moratorium on ocean fertilisation' (ETC Group, 2010: 39).

The exertion of control over geoengineering experiments is also pursued through attempts to **'define legitimacy'**. This is foremost an exercise in demarcating the *legal compliance* of experiments through seeking to identify or develop 'mechanism[s] of legitimacy' (HoC STC, 2010: 75) and investigating 'legal recourse in the event of 'illegitimate' activities' (ETC Group, 2010: 24). Yet, for others legitimacy is a question of either *prohibiting private involvement* in geoengineering experimentation. A past experiment in ocean iron fertilisation has, for example, been deemed 'As much a business experiment as a scientific one' (ETC Group, 2011: 24). Concurrently, recent developments by the CBD have made it so that:

> 'Experiments with a purely commercial background would not constitute 'legitimate scientific research' (FMER, 2011: 134)

On the other hand, it is also recognised that there are imperatives for *protecting private involvement*:

> 'Start–up companies may play an important role in mobilising individual innovation and private capital, and in increasing the rate at

> which effective and low cost technologies may be developed' (Royal Society, 2009: 52).

> 'Where is the investment going to come from, to take the research into demonstration phase and into the marketplace, and there will be a marketplace with a price of carbon dioxide. That is going to be the private sector companies. If we do not allow protection of [intellectual property rights], are we going to actually inhibit that process of investment? So I think I am a little hesitant to simply back the pure public good argument without [intellectual property rights] protection' (participant giving evidence to HoC STC, 2010: 30).

Of course, the possible roles for private involvement will vary not only between different perspectives, but also between the different geoengineering proposals themselves.

The possible conduct of experiments in the global commons or across national boundaries has led to interested parties saying **'let's work together'** in exerting control over geoengineering. Collaboration and transparency are widely seen as virtues amongst the corpus' publications for any form of governance for geoengineering experimentation. Concerns over exceeding *de minimis* levels of experimentation through simultaneous experiments have inspired plans to *coordinate experiments*:

> 'What if a safe amount of aerosols was agreed, for example, but then several different experiments ran simultaneously within the same region of a country?' (SRMGI, 2011: 49).

> 'Wars [could be] waged over the position and density of the clouds, rainfall patterns, ocean alkalinity, and volcanic eruptions as confusion prevails over what phenomena are natural and which are manmade. Different, often conflicting experiments are sponsored by different countries' (US GAO, 2010: 53).

The *risks of unilateralism* in geoengineering experimentation are thus seen to be very real, with past experiments such as those led by Yuri Izrael in stratospheric aerosol injection 'illustrat[ing] the seriousness of… countries unilaterally undertaking atmospheric experiments' (ETC Group, 2010: 11). Others raise alarm over the attribution of blame for any harmful impacts of weather events that might be brought about by unilateral experiments:

> 'Rather than making it possible to identify the causes behind weather extremes in a thermostat–controlled experimental climate, weather event attribution is likely to aggravate the political and ethical conflicts which [the] technology will have unleashed' (Hulme, 2014: 103).

Under this perspective, such experiments cannot be considered 'legally, practically or morally acceptable' (*ibid*: 34) without prior inter–governmental discussion and agreement' (ETC Group, quoted in FMER, 2011: 114).

Society

The fourth theme was concerned with how the public should be engaged with geoengineering experimentation, and what implications such experiments might have for the human condition. The most prevalent framing under this theme was **'let's engage people'**. This was seen as particularly important for 'marginalised populations [who] were likely to be the ones most sensitive to geoengineering experiments' (participant giving evidence to HoC STC, 2010: 31). It was widely reported amongst the corpus' publications that the public should be engaged with geoengineering experiments. Yet, beyond this universal call for engagement, preferences for three quite different forms of engagement can be revealed. The first of these promotes a model of engagement to *consult and inform*:

> ‘A process of dialogue and engagement to explore public and civil society attitudes, concerns and uncertainties’ (Royal Society, 2009: xii)

> ‘Simply relying on traditional means of communicating science (for example, international conferences and science journals) was not seen as satisfactory by our participants, with dissemination needed to national publics (to maintain and build trust) and the local communities close to the test–bed site’ (*ibid*: 454).

Indeed, the model of engagement to inform was captured by members of the public themselves, with those who were engaged as part of the SPICE project test–bed asking:

> ‘How is the test bed being publicized? How will they inform people? What will you tell the local people about it’ (public participants, quoted in Pidgeon *et al.*, 2013: 454).

Others have utilised the imperative to engage people more instrumentally, seeking to elicit a desirable outcome, whether this be to *enable informed acceptance* or to *encourage opposition*:

> ‘Participation… could make any proposed [solar geoengineering] research experiments publicly acceptable and enhance legitimacy’ (SRMGI, 2011: 41).

> ‘Hands Off Mother Earth aims to build a global movement to oppose real world geoengineering experiments’ (HOME, quoted in FMER, 2011: 114).

Geoengineering experimentation is not only a technical intervention in the Earth's climate; **it's a social experiment**, too:

> 'Seeking to manipulate global climate through the use of sunlight reflection methods is nothing short of an ideological project of techno–mastery, justified in the name of science by being declared to be a necessary response to a global climate emergency. It is a project that indeed runs the risk of putting democracy on hold' (*ibid*: 135).

Tightly coupled with the idea that experimentation is deployment, this framing describes new human conditions that will transpire as a result of such experiments, one in which humans are, to borrow the phrase from Macnaghten & Szerszynski (2013), *living the experiment*, as both the (purported) master and subject of a 'perpetual and uncontrollable planetary experiment from which no escape' (Hulme, 2014: 88). It is a condition that would ultimately risk suspending democratic systems of government, through calls to 'put democracy on hold' (James Lovelock, quoted in *ibid*: 135):

Discussion

Beyond technical understandings of experimentation this thematic discourse analysis has revealed a diversity of conceptual themes, framings and sub–frames through which the concept is more broadly understood and used by different participants in geoengineering discourses (Figure 1). In contrast with other social scientific research into framings of geoengineering more generally, framings of geoengineering experimentation are inherently less 'high–level' and more focussed in their scope. Yet, a number of similarities are maintained through this instrumental shift in focus. Framing geoengineering through its possible risks and benefits

(Porter & Hulme, 2013; Scholte *et al.*, 2013; Huttunen & Hildén, 2013) is also prominent in discourses on experimentation through the 'precaution' theme. Governance and justice concerns raised by geoengineering (Porter & Hulme, 2013; Luokkanen et al., 2013; Scholte *et al.*, 2013; Huttunen & Hildén, 2013; Markusson, 2013) are too reflected in more specific experimentation discourses through the 'control' theme. Geoengineering controversy (Scholte *et al.*, 2013) is also visible in experimentation discourses through the 'society' theme. The 'knowledge' theme, however, would appear to be unique to experimentation discourses, used as a justification both for and against geoengineering experiments.

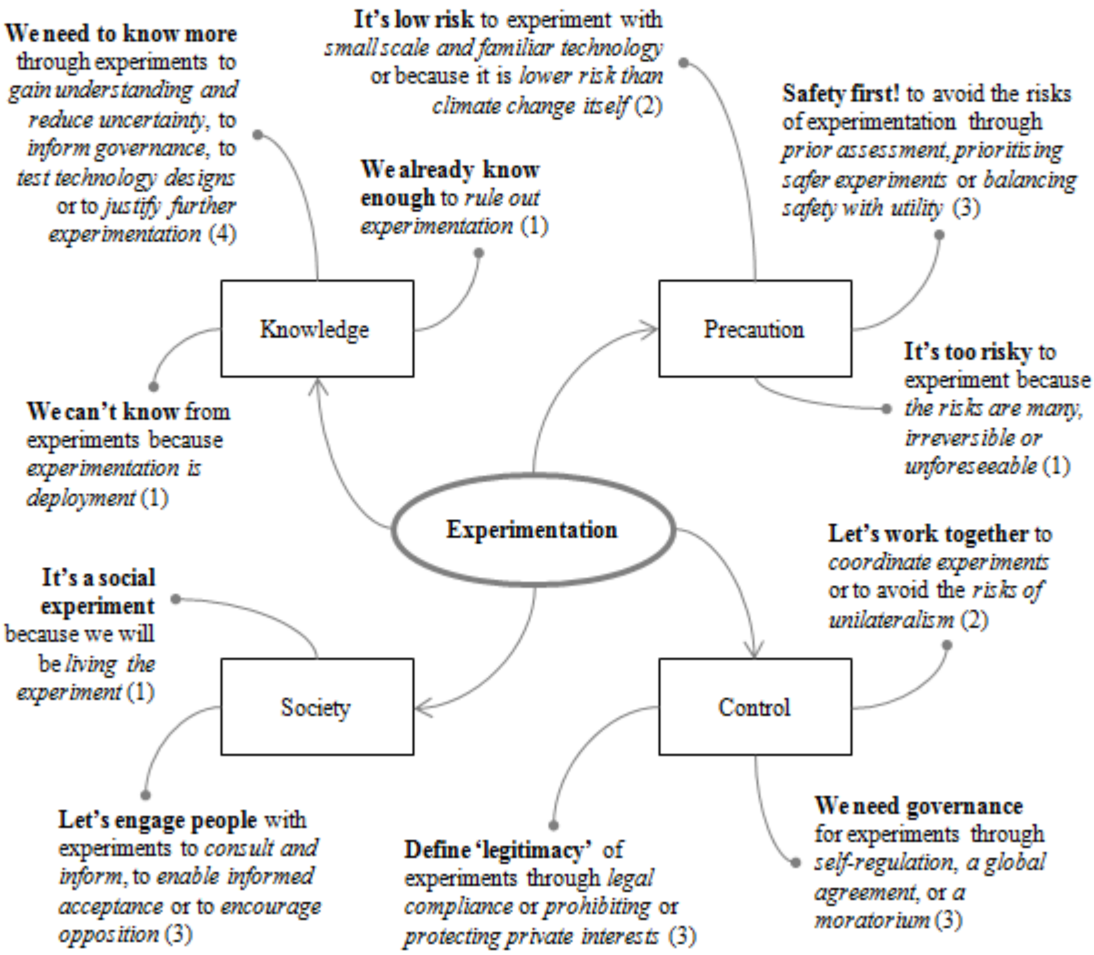

Figure 1 Mapping themes, framings and sub–frames of geoengineering experimentation. The number of *sub–frames* under each **framing** is indicated in parentheses.

In reflecting framings of geoengineering appraisals (Bellamy *et al.*, 2012; Bellamy, 2013), it is clear that corpus publications' are prematurely 'closing down' on experiments for certain geoengineering proposals, chiefly stratospheric aerosol injection. However, it would seem that there remains a sufficient diversity of perspectives over *whether* such experiments should take place, and if they do, *how* they should be governed.

Under the 'knowledge' theme, three competing framings were revealed: 'we need to know more', 'we already know enough', and 'we can't know'. Despite the first and third of these both acknowledging ignorance, the two framings fundamentally disagree about how to respond to such 'non–knowledge' (Böschen *et al.*, 2006). The response for 'we need to know more' is to carry out experiments to reduce ignorance and acquire more knowledge, whereas the response for 'we can't know' is to not carry out experiments in recognition of irreducible complexity. These opposing perspectives originate from divergent 'epistemic cultures' (Knorr Cetina, 1999) that favour control–oriented 'descriptive' and complexity–oriented 'interpretative' styles of knowledge production respectively (Rayner & Malone, 1998; Böschen *et al.*, 2010). Whilst privileging descriptive knowledge much like the 'we need to know more' framing, 'we already know enough' comes to a conclusion that instead aligns with that of 'we can't know', albeit for different reasons: that experiments should not be carried out. In mapping these perspectives, a 'moment of clarity' can be captured before debates about values can be shrouded and replaced by debates about science (Rayner, 2014; Sarewitz, 2004). Yet, it would seem that the existence of an 'experimental gap' between theories, tests and reality will mean that:

> 'It is always theoretically possible to question the results of an experiment as insufficiently representative or inapplicable' (Millo & Lezaun, 2006: 181)

Such conflicting ways of 'co–producing' science and social order (Jasanoff, 2004), can be understood through the cultural co–production of four recurring basic states of knowledge (Swedlow, 2012) that derive from the theory of institutional culture (Douglas, 1970; Thompson *et al.*, 1990; Rayner, 1992). These four cultures constitute sets of shared values and beliefs about science and society. Accounting for the extent to which social control is governed by community structure ('grid') and by the community itself ('group') gives rise to the four cultures: hierarchy, individualism, egalitarianism and fatalism. Hierarchical and egalitarian communities are bound by strong group controls, but diverge under grid controls, bound by strong and weak controls respectively. Concurrently, individualist and fatalist communities are both bound by weak group controls, but diverge under grid controls, bound by weak and strong controls respectively. Through the lens of a cultural interpretation framework (Bellamy & Hulme, 2011; Thompson *et al.*, 1990; O'Riordan & Jordan, 1999; Ney & Thompson, 2000; Thompson, 2008) it is clear that the three 'active' cultural voices: hierarchy, individualism and egalitarianism, are visible throughout the discourses on geoengineering experimentation analysed here.

We have already seen two manifestations of these cultural forms: the respectively hierarchical and egalitarian preferences for descriptive and interpretative styles of knowledge production captured under the 'knowledge' theme. The cultural forms can also be mapped as pervading the 'precaution' theme. The 'safety first!' framing echoes the hierarchical position that nature and climate are seen as perverse / tolerant, and that risk is acceptable, so long as decisions are made by experts. Similarly, the 'it's low risk' framing mirrors the individualist position that nature and climate are perceived as benign, and that risk is low and opportune. At the same time, the 'it's too risky' framing is suggestive of the egalitarian position in that nature and climate are viewed as ephemeral, and that risk is high and could lead to catastrophe. The potential for unforeseeable risks under this framing are yet also reminiscent of the fatalist position, in that nature and climate can be thought capricious and risk deemed unpredictable.

Cultural forms can again be seen within the 'control' theme. Whilst there was general agreement amongst the corpus' publications that if and when it comes to conducting geoengineering experimentation, a 'let's work together' attitude would be favourable, fundamental disagreements emerged under the 'we need governance' and 'define legitimacy' framings. The cases for self–regulation and protecting private interests are made from a quintessentially individualist perspective, supporting academic freedom where outcomes are a personal responsibility, working with the 'grain of the market', whilst blame can be ascribed to individual incompetence. The case for a global agreement and legal compliance, on the other hand, is made from a hierarchical perspective, supporting outcomes that can be managed by the proper authorities through regulation, whilst blame can be attributed to deviants. By contrast, the case for a moratorium and prohibiting private interests is made from an egalitarian perspective, supporting outcomes that instead require altruism and collective effort, whilst blame can be attributed to 'the system' (a combination of hierarchy and individualism). The fatalist position is of course absent from discourses of control, where others are seen as those making the decisions.

One framing under the 'society' theme speaks of conducting geoengineering experimentation as being 'a social experiment'. Building on the notion of a 'slippery slope' from research to deployment outlined under the knowledge theme, the threat of a 'perpetual and uncontrollable planetary experiment' that threatens democratic systems of government is distinctly egalitarian in its construction. Of course, however, the egalitarian conceptualisation of 'democracy' is just one model, and its vulnerability one sociotechnical imaginary (Jasanoff & Kim, 2009). An egalitarian Rousseuaian model of deliberative democracy is contested by competing conceptualisations in the form of a hierarchical Platoian guardian model, an individualist Lockean protective model and a fatalist non–model (Ney & Thompson, 2000). Future research would do well to examine other forms of social experiment that might arise from these different conceptualisations through geoengineering experimentation.

Different conceptualisations of 'participation' were also present amongst the corpus publications, despite a general agreement that a 'let's engage people' attitude was favourable. With reference to Arnstein's (1969) influential 'ladder of participation', the objective to 'consult and inform' people on geoengineering experimentation suggests conceptualisations of participation in decision making that constitute at best 'degrees of tokenism' through 'informing', 'consulting' or 'placating', and at worst 'nonparticipation' through 'manipulation' or 'therapy'. Whilst most perspectives on participation amongst the corpus publications would favour so–called degrees of tokenism, 'manipulation' can also be sought through explicit (e.g. HOME) or implicit (e.g. Mercer *et al.*, 2011) framings that may inadvertently, tacitly or deliberately obscure commitments to securing particular outcomes, be they oppositional or supportive. Whilst the upper echelons of Arnstein's ladder that call for 'degrees of citizen power' reveal a commitment to egalitarian conceptions of democracy in itself, the rationales for deliberation extend beyond the normative to substantive and instrumental ones too (Fiorino, 1990).

It is not surprising then, that such divergent epistemological and institutional cultures contribute to the reasons for why we why we disagree about climate change (Hulme, 2009), and now geoengineering and its experimentation. We disagree about the power and purpose of scientific knowledge; we disagree about the 'right' precautions to take in response to risks that are amplified or lessened in their selection; we disagree about the 'right' way to exercise control; and we disagree about the sort of society that we want to live in and engage with. The possibility for reconciling these conflicting cultures in governance and policy, however, would seem remote. Verweij *et al.* (2006) draw an important insight from such fundamental disagreement: that conflict will be endemic between cultures of at least three divergent but plausible framings. Any governance regime for geoengineering experimentation that adopts a singular framing will therefore be 'at best, partial and, at worst, ineffective or even counterproductive' (*ibid*: 19). In contrast with such ostensibly 'elegant' solutions to complex policy problems, Shapiro (1988) proposed an approach that would accounts for divergent perspectives: so–called 'clumsy' solutions.

Geoengineering experimentation is more than simply a possible scientific procedure: it is a socially constructed and contested phenomenon that demands a new, 'clumsy' approach to its policy and governance. Such an approach should be a plural one developed through a flexible combination of contending framings. In other words, the 'solution space' should account for hierarchical, individualist and egalitarian framings (Figure 2a). Neither descriptive nor interpretative epistemic cultures offer a complete picture of knowledge of experimentation, and therefore their simultaneous pursuit will strengthen policy (Rayner & Malone, 1998). Moreover, their integration through innovative 'analytic–deliberative' methods such as Multi–Criteria Mapping (Bellamy *et al.*, 2013) and Deliberative Mapping (Bellamy *et al.*, in press) will be mutually strengthening (Stern & Fineberg, 1996). Neither hierarchical, individualist nor egalitarian preferred measures of control will be effective alone in the face of risks that are amplified or lessened by the different institutional cultures. Governance should develop decision making powers through proper authorities, with dimensions of expert self–regulation, and with public and stakeholder oversight. In the case of experiments with international, transboundary or commons implications, such as the injection of reflective particles into the atmosphere, for example, a clumsy governance regime might seek regulation through a multilateral organisation such as the CBD, whilst permitting expert self–regulation for 'safe' experiments in an internationally agreed experimental 'allowed zone', whilst having proper stakeholder and public participation in defining those safe levels and in oversight of transparent experimental actions.

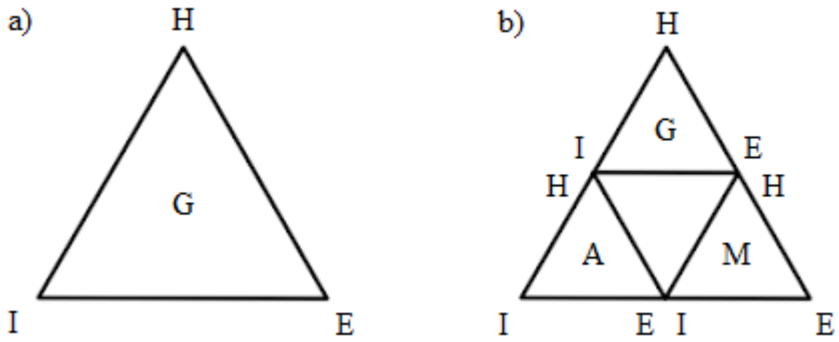

Figure 2 A solution space for a) geoengineering governance and b) climate response governance. After Rayner (2006). Acronyms: hierarchy (H); individualism (I); egalitarianism (E); geoengineering (G); mitigation (M); adaptation (A).

Yet, governing geoengineering and its experimentation forms just one part of a much broader context in climate response governance (Bellamy, 2014). Such activities should not be place in isolation of mitigation and adaptation alternatives, for these too are competing framings at a higher level of aggregation (Bellamy *et al.*, 2012; Stirling, 2008). Figure 2b shows an expanded solution space for broader climate response governance, situating hierarchical, egalitarian and individualist framings in relation to each climate response category. Moreover, they are situated in relation to overall idealised hierarchical preferences for geoengineering, egalitarian preferences for mitigation and individualist preferences for adaptation (Bellamy & Hulme, 2011). Of course, however, these idealised preferences are not universal and would in any case differ in respect to the specific options or proposals being considered within these highly aggregated categories. Indeed, hierarchical framings are driven by an underlying bias towards system maintenance and a preservation of stability, having previously aligned with egalitarian framings in favour of mitigation (Heyward & Rayner, 2013). Geoengineering would appear to have destabilised this alignment, offering the possibility for union with individualist framings.

Conclusions

This article has begun to map the framings of geoengineering experimentation through a corpus approach to thematic discourse analysis. It can be seen that the understandings and uses of 'experimentation' are far more complex than those offered by the Oxford English Dictionary at the start of this piece. Indeed, they are more complex than those eight definitional markers formally offered by the corpus' publications themselves. The four themes of knowledge, precaution, control and society, together with their framings and sub–frames have uncovered competing perspectives that show geoengineering experimentation to be more than simply a possible scientific procedure: it is a socially constructed and contested phenomenon. These perspectives map onto four distinct and divergent epistemological and institutional cultures that compel a new, 'clumsy' approach to policy and governance. I offer a plural, clumsy solution space that would oversee the forging of policy and governance through a flexible combination of contending framings. It is vital that such governance for geoengineering experimentation form part of a broader framework for climate response governance at large. The future of governing geoengineering experimentation will be as much of an experiment as the proposed experiments themselves, and should be implemented in manner that supports ambitions for responsible innovation: to anticipate impacts, to promote reflexivity amongst actors and institutions, to be inclusive of diverse cultural perspectives, and ultimately to be responsive to changing circumstances and societal values.

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