Environmental Science and Policy 83 (2018) 1–10

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

‘Slippery slope’ or ‘uphill struggle’? Broadening out expert scenarios of climate engineering research and development

Rob Bellamy*, Peter Healey

Institute for Science, Innovation and Society, University of Oxford, 64 Banbury Road, Oxford, OX2 6PN, United Kingdom

A R T I C L E I N F O

Keywords:
Climate engineering
Governance
Policy instruments
Research incentives
Scenarios
Slippery slope

A B S T R A C T

It is increasingly recognised that meeting the obligations set out in the Paris Agreement on climate change will not be physically possible without deploying large-scale techniques for either removing greenhouse gases already in the atmosphere or reflecting sunlight away from the Earth. In this article we report on the findings of a scenarios method designed to interrogate how far these ‘climate engineering’ ideas may develop in the future and under what governance arrangements. Unlike previous studies in climate engineering foresight that have narrowly focussed on academic perspectives, a single climate engineering idea and a restricted range of issues, our approach sought to respond to theoretical imperatives for ‘broadening out’ and ‘opening up’ research methods applied to highly uncertain and ambiguous topics. We convened a one-day event with experts in climate change and climate engineering from across the sectors of government, industry, civil society and academia in the UK, with additional experts from Brazil, Germany and India. The participants were invited to develop scenarios for four climate engineering ideas: bioenergy with carbon capture and storage, direct air capture and storage, stratospheric aerosol injection and marine cloud brightening. Manifold challenges for future research were identified, placing the scenarios in sharp contrast with early portrayals of climate engineering research as threatening a ‘slippery slope’ of possible entrenchments, lock-ins and path dependencies that would inexorably lead to deployment. We suggest that the governance challenges for climate engineering should therefore today be thought of as less of a slippery slope than an ‘uphill struggle’ and that there is an increasingly apparent need for governance that responsibly incentivises, rather than constrains, research. We find that affecting market processes by introducing an effective global carbon price and direct government expenditure on research and development are incentives with broad potential applications to climate engineering. Responsibly incentivising research will involve a pluralistic architecture of governance arrangements and policy instruments that attends to collective ambitions as well as national differences and emerges from an inclusive and reflexive process.

1. Introduction

The Paris Agreement on climate change has set out worldwide, legally binding commitments to keeping the increase in global temperature to well below 2 °C above preindustrial levels and to aim to limit the increase to 1.5 °C. Yet, climate modelling research has projected that meeting these obligations will not be physically possible without deploying large-scale techniques for either removing greenhouse gases already in the atmosphere or reflecting sunlight away from the Earth (Azar et al., 2010; Rogelj et al., 2011; Fuss et al., 2014; Gasser et al., 2015). Indeed, one technique – bioenergy combined with carbon capture and storage – is assumed in many of the Intergovernmental Panel on Climate Change (IPCC) stabilisation pathways. Despite growing recognition of this, these ‘climate engineering’, or ‘geoengineering’, ideas are virtually no closer to resembling the sorts of complete sociotechnical systems – assemblages of technical objects and social arrangements that act together as a single system – that would be needed for deployment than they were more than ten years ago when Nobel laureate Paul Crutzen made his influential call for research (2006).

In this article we report on the findings of an expert scenarios method designed to explore how far climate engineering ideas may develop in the future and under what governance arrangements. It contributes to a small but growing literature on climate engineering foresight designed to help decision makers and others plan for the future (Low, 2016; Sugiyama et al., 2017). Foresight methods including the two-axis scenario method (GAO, 2011; Banerjee et al., 2013), forms of structured scenario planning (Boettcher et al., 2015; Haraguchi et al., 2015; Low, 2017) and modified red-teaming (Milkoreit et al., 2011) have been used to explore various aspects of climate engineering

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

https://doi.org/10.1016/j.envsci.2018.01.021
Received 23 October 2017; Received in revised form 29 January 2018; Accepted 30 January 2018
1462-9011/

governance, including how the ideas may evolve in general (Haraguchi et al., 2015; Banerjee et al., 2013), how research in particular may evolve (GAO, 2011), how early movers might influence governance to their advantage (Milkoreit et al., 2011), what effects deployment might have on international relations (Boettcher et al., 2015) and how governance might be adapted to account for a wide range of plausible futures (Low, 2017).

We situate our particular approach to climate engineering foresight in relation to theoretical imperatives for 'broadening out' the inputs to and 'opening up' outputs from research methods applied to highly uncertain and ambiguous topics (Stirling, 2008; Bellamy et al., 2012). Inputs can be judged on the diversity of participating perspectives, options considered and issues raised while outputs can be judged on the degree of plurality and conditionality (reflexivity) with which findings are communicated. While some previous foresight methods applied to climate engineering have engaged with a diversity of participants from across government, industry and civil society (GAO, 2011; Haraguchi et al., 2015), most have only narrowly engaged with academics. With the exception of the scenarios exercise convened by the US Government Accountability Office (2011) which examined non-specific climate engineering, all previous studies have focussed on stratospheric aerosol injection – an idea to reflect sunlight away from the Earth using reflective aerosols – at the expense of a symmetrical treatment of alternatives. While most previous studies involved identifying a broad range of axes and uncertainties that might characterise climate engineering futures, all involved narrowing those down to only a handful of issues. With the exception of one previous study that sought to prescribe unitary policy recommendations (Haraguchi et al., 2015), all were otherwise relatively reflexive in the communication of their findings.

2. Method

Our method sought to continue the tradition of reflexive reporting while at the same time substantially broadening out the diversity of participating perspectives, options considered and issues raised. We convened a one-day scenarios workshop in London with international experts and stakeholders in climate change and climate engineering from across the sectors of government, industry, civil society and academia, drawn primarily from the United Kingdom, but with individual representatives from Brazil, Germany and India (see Table 1). The participants were divided into four heterogeneous groups and each invited to consider two of four climate engineering ideas selected by the research team for their operational diversity and policy relevance. These included two greenhouse gas removal (GGR) ideas: bioenergy with carbon capture and storage (groups 2 and 4) and direct air capture and storage of carbon dioxide (groups 1 and 3); and two sunlight reflection method (SRM) ideas: stratospheric aerosol injection (groups 3 and 4) and marine cloud brightening (groups 1 and 2). Our purpose in developing two scenarios, by two different groups, for each climate engineering idea was to explore uncertainties and ambiguities, to be represented as divergences between the groups' scenarios. In doing so, we hoped to generate a richer array of possible trajectories for the development of climate engineering ideas. In turn, this was to allow us to identify a more diverse set of factors under which the ideas might advance or fail.

Table 1
Scenarios workshop participants.

Code	Group	Occupation
P1	1	Manager at a British innovation consultancy firm
P2	1	Engineering scientist at a British university
P3	4	Deputy head of legal affairs at a Brazilian Government department
P4	2	Chief executive officer at an Indian policy research institute
P5	3	International relations scholar at a German university
P6	1	Marine policy advisor at a British Government department
P7	2	Portfolio manager at a British Research Council
P8	1	Environmental scientist at a British university
P9	3	Climate engineering lead at a British Government department
P10	4	Climate science advisor at a British Government department
P11	2	Freelance British environmental researcher
P12	4	Researcher at a German sustainability research institute
P13	3	Deputy head of strategy at a British Research Council
P14	3	Senior scientist at an international environmental NGO
P15	2	Science and technology studies scholar at a British university
P16	4	Marine scientist at a British marine research centre

The groups were also asked to consider four idealised governance models: self-regulation by climate engineering scientists, engineers or entrepreneurs; global governance (an international agreement for harmonising the conduct of research across countries); principles and protocols (a step-by-step, 'bottom-up' approach to governance); and moratoria to proscribe particular ideas or activities: if, when, and how each might play a role.

By way of preparation, the participants were given access to selected influential writings related to these models in advance, respectively: Keith (2013); Bodle et al. (2014); Rayner et al. (2013) and Hulme (2014). Each group was asked to develop a timeline and narrative storyline for climate engineering research over the next twenty years, considering major events in both the development of the ideas and in their governance. The participants were invited to choose between a forecasting approach (beginning with a 'starting point', and exploring how governance might respond to events) and a backcasting approach (beginning with an 'end point', and exploring how governance may shape events) to the exercise. In practice, all groups opted for the forecasting mode, as they felt that backcasting was too linear and one that required group consensus on an end point from the outset. They were also asked to consider possible branching points where timelines might change course. The groups were facilitated by members of the research team and scribes made detailed qualitative notes on the deliberations. We then undertook observational content analysis whereby themes of discussion were defined during data analysis and derived from the data itself, rather than from external theories, research or interests (Hsieh & Shannon, 2005). Each group also produced a diagrammatic representation of their scenarios (see Figs. 1–4).

In the next two sections we report on the scenarios produced for the four climate engineering ideas under consideration, starting with GGR ideas in section three and SRM ideas in section four. In section five we then discuss the findings in relation to those of other foresight studies and the broader context of climate engineering governance before in section six reflecting on the limitations of our approach and offering plural and conditional recommendations to policy makers for responsibly incentivising research.

3. Scenarios for greenhouse gas removal

3.1. Bioenergy with carbon capture and storage (BECCS)

BECCS is an idea that couples biomass energy generation with carbon capture and storage (CCS) technology to store the carbon dioxide produced in underground geological formations (Gough & Upham, 2011). Scenarios for BECCS were developed by groups 2 and 4.

Group 4 began by noting that BECCS posed a distinctive definitional challenge: it was a combination of two separate ideas put end to end – bioenergy and carbon capture and storage – but one that was not yet fully demonstrated as a single, integrated technology. It was not clear whether, when, and at what scale it could be considered as a climate engineering technology. Group 2 argued that it amounted to putting two already unpopular technologies together, making its eventual uptake doubly unlikely. This was compounded, they argued, by there being very little political lobbying for BECCS, despite its influential role in the IPCC's stabilisation pathways. Indeed, the mismatch between political will and its policy saliency could be seen in the relatively low levels of funding being directed to BECCS research and development (R