UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL, HUMAN AND MATHEMATICAL SCIENCES

How to Govern the Risks of Stratospheric Aerosol Injection Solar Radiation Management

By

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ABSTRACT

FACULTY OF SOCIAL, HUMAN AND MATHEMATICAL SCIENCES

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HOW TO GOVERN THE RISKS OF STRATOSPHERIC AEROSOL INJECTION SOLAR RADIATION MANAGEMENT

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Deliberate large-scale interventions in the Earth's climate system – known collectively as 'geoengineering' – have been proposed in order to moderate anthropogenic climate change. This thesis explores one of the possible technologies, stratospheric aerosol injection solar radiation management (SAI). My original contribution to knowledge is to make a number of interlinked contributions to understanding how interested and affected parties frame and think about SAI risk, and, how its future governance may evolve. The qualitative study addresses two research questions: how might deployment risks be incorporated into SAI governance; and, might SAI governance be plural?

Governance framings are explored through the lens of the technical and social risks of SAI. A theorising of risk by Renn (2008) that incorporates the challenges of uncertainty, ignorance and incertitude, using a typology of risk and a linked risk management model is adopted to explore how SAI risks maybe be incorporated into SAI governance. A conceptual framework of SAI governance, drawing on Bulkeley's (2012) climate change governance theories of consent, consensus and concord, is used to suggest how decision-making might be enacted, and authority negotiated, taken, and given during SAI governance.

Semi-structured stakeholder interviews were undertaken to discern perspectives on SAI risk and risk governance, identifying the underlying rationales, and, providing empirical evidence to assess the theoretical arguments.

Findings describe how SAI governance may take shape and its characteristics. They suggest complex understandings of risk will contribute to the construction of a plural, inclusive and deliberative process of governance that, critically, will evolve in an un-rushed manner over time. The research suggests that risk management theories may help inform how other socially constructed Earth systems might be governed. In addition, the modalities of authorisation and the transnational governing processes proposed by the governance framework appear to provide a useful tool that could help interested and affected parties' understandings of, and participation in, future SAI governance.

The thesis suggests SAI is a useful case study to inform the broader environmental governance debate and the geoengineering-climate change interface. Some suggestions for further research in this direction are suggested.

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DECLARATION OF AUTHORSHIP

I, PAUL IAN ROUSE, declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

How to Govern the Risks of Stratospheric Aerosol Injection Solar Radiation Management.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Signed: ....

Date: ....

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Last, but never least, this thesis is dedicated to the memory of Daphne, Mum, who didn't quite get the opportunity to pass her judgement on the thesis, but who would have been both deeply proud, and relieved that I'd finally scratched the itch.

ABBREVIATIONS

BECS	Bioenergy with Carbon Dioxide Storage
CBD	United Nation's Convention on Biological Diversity
CCS	Carbon Capture and Storage
CEO	Chief Executive Officer
CFCs	Chlorofluorocarbons
CIA	Central Intelligence Agency
CLRTBAP	Convention on Long-Range Trans Boundary Air Pollution
CO_2	Carbon dioxide
COP	Conference of Parties
COP21	21st Conference of the Parties to the UNFCCC
CPP	Catastrophe Precautionary Principle
DAC	Direct Air Capture
ENMOD	Environmental Modification Convention

EPSRC	Engineering and Physical Sciences Research Council
ERGO	Ethics and Research Governance Online
ESRC	Economic and Social Research Council
ETC	Action Group on Erosion, Technology and Concentration
EU	European Union
GC	Global Commons
GE	Geoengineering
GGR	Greenhouse Gas Removal
GHG	Greenhouse Gasses
GMO	Genetically Modified Organism
IMO	International Maritime Organisation
IPCC	International Panel on Climate Change
MCB	Marine Cloud Brightening
N	Number
NASA	National Aeronautics and Space Administration

NERC	Natural Environment Research Council
NDPB	Non-Departmental Public Body
NGO	Non-Governmental Organisation
NSM	New Social Movements
OECD	Organisation for Economic Co-operation and Development
pH	Potential of Hydrogen
ppm	Parts per million
RCUK	Research Councils United Kingdom
SAI	Stratospheric Aerosol Injection Solar Radiation Management
SPICE	Stratospheric Particle Injection for Climate Engineering Research Project
SRM	Solar Radiation Management
SRMGI	Solar Radiation Management Governance Initiative
STFC	Science and Technology Facilities Council
TORF	Tolerability of Risk Framework

UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNFAO	United Nations Food and Agricultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organisation

CHAPTER 1 - INTRODUCTION

1.0 Chapter overview

This chapter introduces the research questions and sets out the structure of the thesis. It defines geoengineering and suggests why it is timely to discuss geoengineering options in the light of anthropogenic climate change adaptation and mitigation progress.

1.1 The research questions

This research addresses how governance may play out in the context of the possible risks of stratospheric aerosol injection (SAI) solar radiation management. The research questions are:

- how might deployment risks be incorporated into SAI governance; and,
- might SAI governance be plural?

Applying theories of risk management and environmental governance, SAI is used as a case study to explore interested and affected parties' perspectives, positions and roles.

1.2 An overview of geoengineering and the response to climate change

Whilst definitions and meanings of geoengineering remain fluid (Bellamy et al., 2013), a definition provided by the Royal Society has generally been accepted. This states that geoengineering is '*the deliberate large-scale intervention in the Earth's climate system, in order to moderate global-warming*' (Shepherd, 2009, p.1). Geoengineering interventions are framed as human engineering solutions to either remove greenhouse gasses (GHG) from the atmosphere or oceans - i.e., Greenhouse Gas Removal (GGR) - or to reduce the amount of solar radiation reaching the planet's surface, known as Solar Radiation Management (SRM)

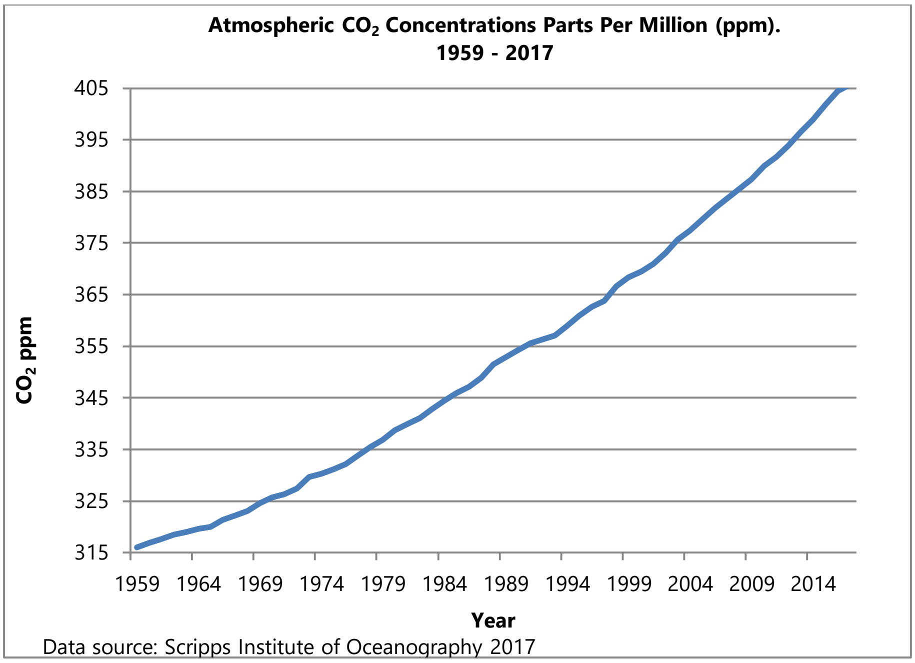
(Lempert and Prosnitz, 2011).

Immediate deployment of any form of geoengineering, if the technology became available, is not currently proposed by any engaged in the debate. However, geoengineering is increasingly being given cautious consideration in climate change management. Key drivers for this have been the International Panel on Climate Change's (IPCC) Fifth Assessment Report (2014), which noted that the globally combined measures to cut GHG to date have had no meaningful effect. The adoption of the Paris Agreement in December 2015 at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (2015) committed parties to holding the increase in the global average temperature to 1.5 °C above pre-industrial levels and, the IPCC Fifth Assessment Report (2014) showed:

- the last three decades have been successively warmer than any preceding decade since 1850 and the sixteen warmest years on record are in the seventeen-year period 1998 – 2014;
- between 1901 and 2010, global mean sea level rose by 19 cm, faster than in the previous two millennia;
- the mean global combined land and ocean surface temperature rose by 0.85°C between 1880 and 2012;
- there has been a 26% increase in ocean surface acidity corresponding to a 0.1 reduction of pH; and,
- Arctic sea ice extent has decreased in every successive decade since 1979.

IPCC has >99% confidence that these changes are a result of Anthropogenic GHG emissions.

Figure 1.1 Historic atmospheric carbon dioxide (CO_2) concentrations 1959 – 2017



To date, globally combined measures to cut GHG have had minimal effect. Despite the 1992 UNFCCC (1992) binding commitment to stabilise atmospheric GHG concentrations at a level that would prevent dangerous anthropogenic effects on the climate system, total anthropogenic GHG emissions have continued to increase (see Figure 1.1), and there were larger absolute increases between 2000 and 2010, aside from a small reduction in 2008 during the financial crisis. In November 2017, there were 405.7 parts per million (ppm) of carbon dioxide in the Earth's atmosphere, an increase of 3% (or 11.8 ppm) over the past five years (Keeling et al., 2017). Although there has been declining growth in carbon dioxide emissions between 2013 and 2015 (Olivier et al., 2016) this is still an increase, despite a growing number of climate change mitigation policies adopted both globally and at the nation-state level, in addition to the UNFCCC commitments.

The burning of fossil fuels not only drives climate change but also the global economy. It is a deeply embedded social and cultural practice and achieving reductions will be extremely challenging, with or without globally ratified commitments. To accomplish, within the required 35 years, the deep structural, social, economic and infrastructural change required to deliver the 40 to 70%

reduction of global GHG emissions necessary to constrain warming to 2°C (let alone 1.5°C), demands a massive global effort and investment (IPCC, 2014). However, critically, even if this were achieved it would not mean an end to anthropogenic climate change because the emissions to-date will continue to have effect for hundreds of years. If, for example, humanity were to achieve a complete cessation of net anthropogenic carbon dioxide emissions by 2100, temperatures, would be maintained at the 2100 level (i.e., plus 2°C) and persist at that level for many centuries.

The remarkable challenges that reducing emissions bring do not justify the use of geoengineering. However, it may be sufficient to suggest that some consideration of what a geoengineering approach might look like and how it might be governed is increasingly warranted. Indeed, 101 of the 116 IPCC Fifth assessment climate scenarios include the use of geoengineering to avoid an overshoot in emissions targets beyond the 1.5°C target (IPCC, 2014). It is on this basis that this study focuses on geoengineering.

1.3 Stratosphere Aerosol Injection Solar Radiation Management (SAI)

SAI is one of a number of potential approaches to SRM that include, for example, the planting of reflective crops, cloud whitening, enhancing urban surfaces' albedo and the installation of mirrors in geo-stationary orbit. As the focus of this research, SAI is briefly introduced here; however, the full range of potential geoengineering technologies, their strengths, weaknesses and potential risks are reviewed in Chapter 2.

SAI would involve the use of stratospheric aerosols to enhance solar forcing, creating a global dimming effect. SAI, which is currently considered the most tractable of the potential approaches, and may be the 'first mover technology' (Bellamy et al., 2013, Jones et al., 2013, Keith, 2013), would intentionally and fundamentally change the global commons (GC) of the atmosphere, creating a new governance realm.

Being able to cool the entire planet by injecting in the order of 10,000 tonnes of highly efficient aerosol into the stratosphere, an amount that could potentially be delivered in a month by a single heavy lift stratospheric aircraft (Keith, 2013), is *prima face* an appealing solution to climate change. However, it raises fundamental, and in some cases entirely new, ethical, social and environmental concerns and challenges. These inform, and are informed by, wider debates about the future of the human-nature relationship in the Anthropocene including ethical responsibility, the role of technology and science, equality and democratic inclusion, risk and, critically, governance.

SAI would be the first technology with the capacity to create a new relationship between humans and the Earth, reengineering the terms of engagement between society and nature, for the first time bringing a planetary system under our control (Macnaghten and Szerszynski, 2013). Although human activity has caused unintended changes to Earth's systems, SAI technology will, for the first time, allow humans intentionally to control key elements of the system. This intentionality is one of the key factors that differentiates SAI from other large-scale disruptive technologies.

1.4 Thesis overview

This thesis focuses on a sub-set of this agenda, exploring how risk management and environmental governance of SAI, as a globally risky technology, might play out. Particular attention is paid to how interested and affected parties function in the context of uncertainty. A theoretical framework examines the meaning of governance, and the extent to which there is a governance framework fit for purpose for SAI, concluding that there are currently no suitable governance, or indeed regulatory, frameworks capable of providing a model under which SAI could operate. The research explores how governance might be established, paying particular attention to the role of risk, risk management and the functioning of authority within future governance of SAI.

An analysis of SAI, and wider geoengineering literature, suggests that risk has not been comprehensively incorporated into past SAI governance analysis. This thesis seeks to address this using a theorising and typology of risk management that includes the challenges of uncertainty, ignorance and incertitude in its analysis (Renn, 2008). Given the complex understandings of risk the study then explores how future governance of SAI might evolve. A governance theory (Bulkeley, 2012), that allows for the incorporation of divergent perspectives and a complexity of contributions from a wide range of interested and affected parties (which the risk analysis suggests is likely to be present in SAI debate), is used.

Having theorised a possible SAI governance trajectory, a pilot study tested and refined the research method after which 30 senior stakeholder interviews were conducted to examine whether the theory is fit for purpose, and what future governance of SAI might look like. Following a detailed analysis of the evidence, findings are presented and a picture of how SAI governance may evolve is offered. In conclusion, there is a discussion of the findings and how they inform future SAI and other global environmental governance questions. Some suggestions for future SAI research are also offered.

Structurally, the thesis reviews geoengineering options in Chapter 2. The governance issues that pertain to SAI, and the literature about these are discussed in Chapter 3, whilst Chapter 4 provides an overview of the theoretical framework, including interpretations of risk and how the governance of SAI might operate. Chapter 5 discusses the research methods adopted and the analysis and findings based on interviews are presented in Chapters 6, 7 and 8. A discussion of the findings and their wider meaning are explored in Chapter 9, before the conclusions are presented in Chapter 10.

CHAPTER 2 - REVIEW OF GEOENGINEERING OPTIONS

2.0 Chapter overview

This chapter reviews the range of geoengineering techniques and compares each technology's potential effectiveness, costs, constraints and risks. It is argued that SAI is currently the most promising technology and it is therefore an appropriate case study for this research. In the light of this decision, SAI is described in some detail and a review of the technology identifies the key risks associated with any future deployment.

2.1 An overview of geoengineering

Geoengineering has been an area of academic study since the 1970's (Marchetti, 1977) but more significantly since the early 1990s, and it is increasingly being taken seriously as a potential response to climate change. Much of this interest was stimulated by the work of institutions such as the Royal Society and the American Meteorological Society (Shepherd, 2009, AMS, 2009). However, new actors are increasingly entering the debate, adding impetus to, and shaping, the direction of research.

Geoengineering technologies are characterised by either the objective of the technique, or their location of operation (Zhang et al., 2015). They are termed land-based, ocean-based, atmosphere-based, and Space-based techniques, or Greenhouse Gas Removal (GGR), and Solar Radiation Management (SRM) methods. In this chapter the potential methods are grouped by technique rather than geography.

In brief, GGR technologies seek to remove GHG, normally carbon dioxide, from the atmosphere to reduce the planetary atmospheric concentration of the gases. The amount of material involved is exceptionally large. Current estimates indicate that humanity releases 36 Gigatons (36,000,000,000 tonnes) of carbon dioxide annually (IPCC, 2013). In addition, a further 9.4 Gigatons of other GHG, in the form of Methane, Nitrous Oxide and fluorinated gases are also released annually (IPCC, 2013). For any single GGR technique to begin cooling it would therefore need to remove, and store sufficient greenhouse gas to offset the annual 45.36 Gigatons of GHG emissions.

SRM techniques seek to reflect solar radiation away from Earth, reducing radiative forcing. SRM would cool in a similar way to a cloud passing over the sun, creating shade and briefly cooling the shaded area. The Royal Society review of geoengineering estimated, in broad terms, that around 2% of the total radiative forcing of the Sun would need to be redirected to counter the effects of the doubling of carbon dioxide concentrations in the atmosphere (Shepherd, 2009). GGR and SRM geoengineering techniques are now reviewed. This review is summarised in Tables 2.1 and 2.2 which highlight the relative merits of each approach.

2.2 Greenhouse Gas Removal Geoengineering approaches

GGR approaches include chemical weathering, biochar production, large-scale afforestation and re-forestation, bioenergy with carbon dioxide storage, direct air capture, desert bio-geoengineering, ocean up-welling and ocean fertilisation techniques. Evidence suggests GGR methods are less risky than SRM approaches with fewer side-effects (NERC, 2016). Many can be contained within nation state boundaries, giving rise to less challenging governance issues (Keller et al., 2014). However, to-date GGR is only expected to be able to sequester small quantities of GHG in comparison to projected anthropogenic emissions, and none is expected to have the capacity to reduce mean surface temperature for many decades (Zhang et al., 2015, Shepherd, 2009).

Enhanced natural chemical weathering of rocks can reduce atmospheric carbon dioxide concentrations as rain reacts with the rock producing calcium. This is carried into the oceans (Burner et al., 1983). If humans could accelerate this process, theoretically it has the potential to change the carbon cycle sufficiently to remove some anthropogenic carbon dioxide.

Currently, the mineral Olivine is considered the most tractable weathering agent (Shepherd, 2009). It could be mined on an industrial scale, ground up, and spread over land, thereby speeding up the chemical reactions and 'sucking' carbon dioxide out of the atmosphere. In theory, one kilogram of Olivine sequesters about one kilogram of carbon dioxide (Cressey, 2014).

However, it is not a viable method on the scale needed. The actual efficiency of carbon sequestration would be far lower than the potential, because of the GHG costs of mining, preparation and grinding, distribution and spreading of the mineral. The volumes of mineral required would be vast. Hangx and Speirs (2009) estimate to achieve a 30% annual offset of global carbon dioxide emissions 5 Gigatons of Olivine would have to be spread annually, requiring a globalised infrastructure and an internationally co-ordinated effort. Further, currently there is no market to reward the investments required. Resolving these challenges may well be more challenging than adopting the equivalent adaptation and mitigation measures.

Biochar production requires pyrolysis to create charcoal or black carbon which is subsequently applied to soil as a long-term sink for atmospheric carbon dioxide (Lehmann et al., 2006). It is, in effect, a carbon sequestration measure, but one that may have additional benefits of increased crop and vegetation productivity, which, if left in situ and not burnt or otherwise converted, would sequester carbon from the atmosphere. However, there is no capacity for its production to deliver climate level net cooling (Sharma-Sindhar, 2014).

Large-scale afforestation and reforestation would increase the carbon store of carbon dioxide in plants and soil microbial life and there are no technical development costs. However, competition for afforestation and reforestation for geoengineering with other land uses, especially agriculture, will be strong (Shepherd, 2009). Currently up to 58,000 thousand square miles of forest are lost every year accounting for 1.5 Gigatons per annum of lost sequestered carbon (Szalay, 2014). To afforest at sufficient rate to balance annual emissions would require over 30 times the land mass currently deforested be afforested, annually, requiring a global shift in agricultural and land-use practices (Canadell and Raupach, 2008).

Bioenergy with carbon dioxide storage (BECS) combines bioenergy and Carbon Capture and Sequestration (CCS) to generate energy and reduce GHG emissions. (NERC, 2016). BECS is technically feasible and there are some real-world examples in operation (Obersteiner et al., 2001). However, BECS is not in the true sense a geoengineering technique as it would not be a deliberate direct, large-scale intervention in the Earth's climate system (Shepherd, 2009), rather it is the evolution of a suite of approaches to reduce reliance on fossil fuels and capture GHGs.

Desert bio-geoengineering would take the form of afforestation. However, alone it could not lead to climate cooling. If half the available desert were afforested this has a theoretical capacity to sequester 11 Gigatons of carbon dioxide per annum, representing less than 30% of global anthropogenic GHG emissions per annum (IPCC, 2013). Massive new irrigation systems would be required, perhaps using energy-hungry desalination plants. The weather, regional climate, biodiversity and ecosystems services effects are uncertain (Manfready, 2011).

Ocean based geoengineering. The volumes and scale of the Earth's oceans' capacity to sequester and hold carbon suggest a large potential for geoengineering development (Raven and Falkowski, 1999). Ocean fertilisation, adjusting ocean alkalinity and adjusting ocean currents have been suggested as possible ocean based GGR approaches (Zhang et al., 2015).

It would be possible to **increase the oceans' carbon carrying capacity** and accelerate the carbon uptake by introducing lime. However, the volume of lime required would demand a global mining enterprise of unprecedented scale. In addition, the ecological consequences could effect the entire ocean biosphere (Zhang et al., 2015).

The rate at which atmospheric carbon is transferred to the deep sea could be altered by adjusting **ocean upwelling and downwelling**. However, the engineering challenges are substantial. Zhou and Flyn (2005), for example estimated that increasing downwelling by 1 million cubic meters a second would only increase carbon uptake in the oceans by 0.01 Gigatons per annum, 360 million times less than annual human carbon emissions (IPCC, 2013) meaning that it is not currently practical in engineering terms, even in principle.

Ocean fertilisation would increase the rate of growth of marine phytoplankton, which fixes carbon from the oceans' surfaces, a proportion of which settles under gravity in the deep ocean. This has a strong influence on atmospheric carbon dioxide concentrations (Vaughan and Lenton, 2011). Sarmiento and Gruber (2002), for example, note that if the mechanism stopped, atmospheric carbon dioxide concentrations would increase by 100 ppm within ten years.

Marine phytoplankton growth could be accelerated by the introduction of additional iron (Zhang et al., 2015, Williamson et al., 2012). Which, if done at scale, could enhance carbon sequestration sufficiently to reduce atmospheric carbon dioxide concentrations (Williamson et al., 2012). Rickles (2009), for example, showed that a ten-year programme of ocean iron fertilisation in the Southern Pacific Ocean could take up an additional 2.2 Gigatons of carbon. However, this is 163 times less than the expected anthropogenic carbon emissions over the same time period (IPCC, 2013).

Iron fertilisation has been deployed for various reasons, providing some insights into how reactions to geoengineering may play out. A case study of one of these, the Haida Gwaii project, is given at Annex 1.

Direct air capture (DAC) - the sequestration of GHG directly from ambient air - is generally considered one of the least controversial but also the most technologically challenging techniques (Shepherd, 2009). Three approaches are proposed by Broehm (2016). First, using an aqueous solution of a strong base to take up carbon dioxide, this would then be separated in a sequestrable form. Secondly, using adsorbents to remove carbon dioxide and, thirdly, inorganic zeolites could take up carbon dioxide. However, no suitable materials have been identified to-date to deliver scale DAC, expectations of discovering one are currently low (Goeppert et al., 2012, Stuckert and Yang, 2011, Broehm et al., 2016), and there is currently no expectation that it will be deliverable until the post 2030 – 2050 period (Gale, 2015).

Table 2.1, summarises the effectiveness, constraints, costs and risks of the GGR techniques discussed to this point.

2.3 Solar Radiation Management techniques

The Sun's intensity cannot be changed; it is an external driver beyond human control. SRM techniques seek to reduce the intensity of sunlight reaching the Earth's surface in ways similar to albedo from cloud and other reflective natural surfaces.

SRM technologies could have a measurable cooling effect but might also have regional climate and other effects (Robock, 2008, Stilgoe, 2015, Jones et al., 2017). They would also generally operate across nation state boundaries and within the Global Commons, raising both risk and transboundary governance issues (Victor et al., 2009a). Some of the potential technologies may be considered highly risky, depending on how they are deployed and to what extent.

Table 2.1 The feasibility and practicality of differing approaches to greenhouse gas removal geoengineering

Legend: HIGH MEDIUM LOW

TECHNOLOGY	EFFECTIVENESS	CONSTRAINTS	COSTS	RISKS
ENHANCED CHEMICAL WEATHERING	16.6 Gigatons of ground and distributed Olivine could theoretically balance Anthropogenic GHG emissions (Hangx and Spiers, 2009).	A global industrial complex to produce 7 Km3 of mineral per annum - (Shepherd, 2009). Access to land to spread the mineral and the loss of land for other use. High energy production costs.	Very high infrastructure and distribution costs. No market mechanism to reward the required investment.	Possible changes to the pH of fresh water, harming organisms (Hartmann et al., 2013).
BIOCHAR	Not capable of producing climate cooling (Lehmann et al., 2006).	Marginal benefits of increased crop and vegetation productivity (Sharma-Sindhar, 2014).	High infrastructure costs (Lehmann et al., 2006).	Minimal risks (NERC, 2016).
AFFORESTATION AND REFORESTATION	To cool 390,000 Km2 would require afforesting per annum, a surface area larger than Germany. (Szalay, 2014).	Requires a global shift in agricultural practices, land use and ownership (Canadell and Raupach, 2008).	High cost of land use change. Prohibitive irrigation cost (Shepherd, 2009).	Disputes about land use change.
BIOENERGY WITH CARBON DIOXIDE STORAGE	Not capable of producing climate scale effects (Shepherd, 2009).	Take up of carbon capture technology must be rapid and at large scale to affect carbon concentrations. Requires a scale move away from the use of fossil fuels (NERC, 2016).	Restructuring the fossil fuel industrial complex. Building efficient energy plants and changing land use.	Few risks.
DESERT BIO-ENGINEERING	A maximum theoretical capacity to sequester 20% of Anthropogenic GHG emissions annually (Ornstien et al., 2009).	Requires 6 million Km2 be engineered raising questions about land use and ownership. A new continental scale irrigation system required to supply water to arid deserts (Ornstien et al., 2009).	Re engineering water supply at extremely large scale. Land may require purchasing (Gaskill, 2004).	Regional climate, biodiversity and ecosystem effects. Trans-desert spread of disease, e.g. avian flu (Manfready, 2011)
OCEAN UPWELLING & DOWN WELLING	Theoretical capability of producing climate cooling (Zhang et al., 2015).	The engineering challenges of increasing upwelling and downwelling are very substantial and it is not currently practical, even in principle in engineering terms, to deliver cooling (Zhou and Flynn, 2005).	Extreme energy demand to drive multiple pumps/ heat exchangers, each larger than any pump yet designed (Zhou and Flynn, 2005).	Unknown.
OCEAN FERTILISATION	A ten year programme of ocean iron fertilisation could take up 163 times less carbon than that emitted by humans (Rickles et al., 2009).	The capacity to produce and distribute sufficient iron. Limited understanding of where and how to best distribute the iron (Williamson et al., 2012).	Costs of production, transport and distribution of Gigatons of iron fertiliser would be high, but is unknown.	Reduced ocean productivity; oxygen decrease; ocean acidification change; and, ecosystems damage (Wallace et al., 2010).
DIRECT AIR CAPTURE	A theoretical capacity to deliver climate cooling (Broehm et al., 2016).	No solutions have been identified with a theoretical capacity to deliver cooling. (Goeppert et al., 2012).	Currently unknown.	Could affect plant growth, very low risk (Broehm et al., 2016).

SRM would not reduce the warming effect of GHG radiative forcing. Neither would it counter all the effects of all the GHG all of the time, because it would only be effective during hours of daylight (and summer at high latitudes). Because solar forcing is diurnal, and varies at different latitudes, altitudes, as weather changes, and in response to a range of other factors, a simple perfect reflective surface of 10.2 million square kilometres (2% of the Earth's surface area) would not deliver the required cooling in a stable fashion (even if such a structure could be built and a politically acceptable location found to site it). The consequences of such an intervention on precipitation, weather, ecosystems and ecosystems services and biodiversity would be complex, global and highly risky (Russell et al., 2012).

The underlying cause of global warming (increased GHG concentrations) would remain in situ, increasing or decreasing depending on human activity and natural phenomena. This raises important questions about the longevity of any SRM intervention and how an 'on / off switch' might function. Importantly, SRM methods would have no effect on ocean acidification and, because the climate system is more complex than current climate models, unintended consequences of scale deployment should be expected (Russell et al., 2012). Various proposed technologies are now discussed and Table 2.2 summarises the effectiveness, constraints, costs and risks of these.

Land-based enhanced albedo measures would seek to make the surface of the planet as a whole more reflective, returning solar radiation to space. Described as the 'White Roof Method' by Zhang (2015), structures could be built using light coloured materials and existing structures re surfaced to enhance albedo. However, the net temperature effect of this measure is likely to be trivial, or one of warming, as locally affected surfaces would constrain moisture transport, and hence diminish cloud formation, meaning that more solar radiation would reach the Earth's surface (Jacobsen and Hoeve, 2012). The Royal Society review estimated the direct cost of painting structures and surfaces sufficiently white to reduce temperatures would be

$300Bn per year, making the White Roof Method one of the least effective and most expensive of all possible geoengineering approaches (Shepherd, 2009).

It could be possible to **enhance plant albedo** through selective breeding and by genetically modifying plants (Ridgwell et al., 2009). The direct costs of, and mechanisms to deliver, the required change in cropping practice have not been estimated in any detail, and the effects of the required changes on disease resistance, growth rates, market price of food and drought tolerance are uncertain. In the context of a world struggling to grow and distribute sufficient food (UNFAO, 2009), the challenges of diverting effort toward crops with enhanced albedo could be too great to make this a practicable option.

Large-scale enhanced albedo in deserts, through the use of reflective surfaces, could have the potential to deliver cooling (Gaskill, 2004). However, the manufacture, transport and installation of the materials to cover thousands of square kilometres would create significant new carbon emissions. The reflective surface would need to be frequently cleaned requiring irrigation in deserts. The cost of covering sufficient land surface could be several trillion dollars per annum (Shepherd, 2009).

Latham has suggested that marine clouds could be brightened using aerosols, produced from seawater (Latham et al., 2012). Known as **Marine Cloud Brightening** (MCB), Rasch (2009) has estimated that it is in principle possible to enhance the reflectivity of clouds to a value approximately equal to a balancing of the forcing of a doubling of present carbon dioxide concentrations. However, significant technological and scientific questions remain unresolved (Latham et al., 2008); including, cloud micro-physics and dynamics (Kravitz et al., 2014), the nature of the sea-going hardware to deploy the aerosols at scale, and how different aerosol processes might affect particle formation and dispersion (Connolly and McFiggans, 2014, Maalick et al., 2014). In addition, the potential effects of MCB on the environment and ecosystems could be significant, including driving changes to ocean productivity and circulation patterns such as El Nino and monsoon cycles (Jones et al., 2009, Russell et al., 2012).

A range of **Space based techniques** exist. They do, however, contain such great uncertainties in techniques, direct and economic costs, risks and effectiveness as well as lengthy timescales that their implementation in the next hundred years is probably not realistic. For example, deployment would require a 3 million square kilometres reflector to be located at the Lagrangian Point (Angel, 2006) 1.5 million miles from the Earth's surface (Cain, 2017). Or a 5.5 square kilometres reflector could be placed in near Earth orbit, to achieve the 2% reduction in solar radiation required (Angel, 2006). The largest object in near Earth orbit is currently the International Space Station. It is 110m long, cost over $100 billon and took 14 years to build (NASA, 2017).

Stratospheric Aerosol Injection SRM, is the final geoengineering approach currently discussed in the literature (Zhang et al., 2015, Caldeira et al., 2013) and because it is currently considered the most tractable technology option, with the probable greatest potential for effectiveness (Keith, 2013), and gives rise to some of the most interesting governance issues, it is the subject of this thesis.

Aerosols would be deployed in the stratosphere which is located at between 7 and 15 kilometres above sea level depending on latitude at the time of measurement (Labitzke and Van Loon, 2012), rather than the lower, and easier to access, troposphere (Robock et al., 2009). The stratosphere is a relatively stable zone in the atmosphere where there is less vertical than horizontal mixing, meaning an aerosol particle could remain in situ, reflecting solar radiation for a period measured in years. If the injection were to take place in the troposphere particles would quickly be caught in turbulent air, and fall back to ground level in a matter of weeks (Keith, 2013). Tropospheric aerosol injection with equal efficacy to stratospheric injections would therefore require continuous injection of massive quantities of aerosol that

Table 2.2 The feasibility and practicality of differing approaches to solar radiation management geoengineering **Legend:** HIGH MEDIUM LOW

TECHNOLOGY	EFFECTIVENESS	CONSTRAINTS	COSTS	RISKS
ENHANCED ALBEDO 'WHITE ROOF METHOD'	Trivial localised cooling only, with potential for warming due to diminished cloud formation (Jacobsen and Hoeve, 2012).	The manufacture and transport of the whitening products. Compliance with whitening on private property (Zhang et al., 2015).	In the order of £300 billion (Shepherd, 2009)	Could create regional warming
ENHANCED PLANT ALBEDO	A 4% increase in plant albedo could deliver a theoretical cooling of one degree (Ridgwell et al., 2009).	Capacity for genetic modification of 4% of all plant life on Earth is low. Current, and possible future bans on use of GMOs, political and social challenges.	Unknown, expected to be very high (Shepherd, 2009)	Effects on disease resistance, growth rates, market price of food and drought tolerance are uncertain (Ridgwell et al., 2012)
ENHANCED DESERT ALBEDO	If delivered at sufficient scale cooling would be theoretically possible (Gaskill, 2004).	The manufacture, transport and installation of materials would create significant new carbon emissions. Cleaning the reflective surface would require state scale irrigation infrastructure workforce.	Extremely high - several trillion dollars per annum (Shepherd, 2009)	Regional climate affects, including on water supply. Land conflict and uncertain ecological impacts (Gaskill, 2004).
MARINE CLOUD BRIGHTENING	In principle possible to enhance the reflectivity of clouds to a value approximately equal to the forcing of a doubling of present carbon dioxide concentrations (Rasch et al., 2008)	Significant technological, scientific and modelling questions remain unresolved. The nature of sea-going hardware is unknown (Kravitz et al., 2014, Connolly and McFiggans, 2014).	Potential to be in order of £1 billion per annum (Launder 2009).	Changes in precipitation with potential impacts on the Amazon rainforest and El Nino formation. Effects on atmospheric circulation; terrestrial biochemical and ocean chemical cycling; surface temperature gradients; increased deposition of sea spray to land; and, unknown effects on ocean species (Russell et al., 2012).
SPACE BASED TECHNIQUES	Potentially highly effective with a capability to counter all anthropogenic warming (MacKerron, 2014).	Engineering constraints - constructing shades of up to 3 million Km2 in space is currently beyond any capability (Angel, 2006).	Costs will be extremely high, over one trillion dollars (Keith, 2013)	Potentially the lowest risk option, aside from potential rocketry failures (MacKerron, 2014). However, the moral hazard challenge would remain.
STRATOSPHERIC AEROSOL INJECTION	High potential for effectiveness, capable of delivering cooling quickly (Keith, 2013).	The detail of delivery mechanisms to be finalised. Aircraft are capable of deploying at scale (Morton, 2015).	Low, cancelling the effects of a doubling of GHG concentrations would cost £25-50 billion (Crutzen, 2006a)	The potential for: damaging shifts in rainfall patterns; a reduction of ozone; drought; migration; and, well-being affects due to loss of blue skies (Robock et al., 2009).

would continuously fall out, causing large-scale air pollution, related deaths, and acid rain.

Whilst a wide range of aerosols could be released and scatter light, sulphates, alumina, diamond and calcites are currently considered the most useful SRM particles (Stilgoe, 2015, Keith, 2010, Jones et al., 2016). Particle size is a key driver of this particle choice because the aerosol needs to be as 'reflective' as possible and it should remain in situ and stable for as long as possible (Rasch et al., 2008). The larger particles are (larger than two tenths of a micron), the less effective at scattering light they become for a given mass deployed. Larger particles also condense, coagulate and increase in size more quickly than smaller particles and therefore fall faster, and faster still as they grow. This means, for example, that injected sulfuric acid is expected to be more effective than sulphur dioxide, which would oxidise slowly into sulphuric acid after injection, forming larger particles. Questions about which particles would be optimal in SAI remain unresolved and require further research and modelling.

The delivery mechanisms are also unresolved, although aircraft delivery is expected to be the most practicable and economic method (Robock et al., 2009, Keith, 2013, Stilgoe, 2015). To be fully effective, planes would need to fly at approximately 65,000 feet and be fitted out with spraying kit to deliver particles. Nozzles to eject aerosols of the desired size are feasible but have not actually been developed, nor is there a supply chain for the specific compounds in place. However, Keith (2013) argues that Gulfstream business jets could be retrofitted with low-bypass military jet engines that would allow for minimal deployment.

The two key factors that drive interest in SAI as the pre-eminent potential geoengineering technique are the rapidity with which it would take effect, combined with the high potential cooling efficiency and low direct cost of deployment. The Council on Foreign Affairs (CFA, 2009) suggests that 1 kg of sulphur situated in the stratosphere could offset the warming effect of several hundred thousand kilograms of carbon dioxide. Keith (2013) has calculated that the additional radiative forcing of the 240 billion tonnes of carbon released by human activity since the beginning of the industrial revolution could be reduced by half by an annual injection of 1 million tonnes of aerosol, meaning that SAI has very large leverage over anthropogenic carbon climate forcing. If a fleet of 20 Gulfstream aircraft were deployed they could deliver sufficient radiative forcing to produce detectable climate cooling (Keith, 2013). Larger scale effects would require more complex aircraft solutions, but these could be found by adapting the existing technology that is available in, for example, the U2 aircraft that has been flying at 70,000 ft. collecting atmospheric science data and intelligence since 1950.

The relative ease of implementation, combined with the radiative efficiency of aerosols, suggests the direct costs of SAI would also be low, relative to cutting emissions (Brahic, 2009), or other approaches to geoengineering. Crutzen estimates the annual direct cost of sufficient SAI to counteract the effects of a doubling of carbon dioxide concentrations would be in the order of $25-50 billion per annum (Crutzen, 2006b), over 100 times cheaper than producing the same temperature change by reducing carbon dioxide emissions (Keith, 2013). The Royal Society review suggests SAI and MCB would be 1,000 times less expensive than other geoengineering options and, even if their direct costs rose by 100 fold, there would still be a large financial advantage over mitigation (Shepherd, 2009). Perhaps most optimistically, Keith (2013) suggests SAI could be cheap enough to mean the cost would be a minor consideration. Whilst MacKerron (2014) has drawn attention to the importance of indirect economic cost over direct cost - drawing parallels with SAI and the nuclear industry that was allegedly going to provide energy 'too cheap to meter' (Strauss, 1954), but which now requires state subsidy to maintain.

2.4 Timescales

Timescales are an important factor in the discussion of geoengineering techniques. SAI has the capacity to cool the Earth's climate very quickly whereas other techniques, in particular GGR, would take longer. These differences will have an important influence on technology choice and its governance. Timescales are identified in Table 2.3.

Table 2.3 Timescale definitions

TIMESCALE	DEFINITION
Short-term	Up to 10 years
Medium-term	10 to 30 years
Long-term	>30 years

The ability to cool the entire planet by injecting 10,000 tonnes of highly efficient aerosols, an amount that could potentially be delivered in a month by a single heavy lift stratospheric aircraft, is *prima face,* an appealing solution to climate change in the light of increasingly challenging GHG reduction targets and failures to date to meaningfully reduce GHG emissions. In addition, the rapidity of SAI effects, which is in marked contrast to GGR techniques, all of which are expected to require decadal time scales to deliver any cooling, lend appeal. However, the potential risks of SAI are complex and multilevel (USGAO, 2010, Shepherd, 2009, SRMGI, 2011, Long et al., 2011, Asilomar, 2010, Stilgoe, 2015, Effiong and Neitzel, 2016, Morton, 2015, Ferraro et al., 2014, Jones et al., 2017). These risks are now reviewed.

2.5 Stratospheric aerosol injection risk review

The current knowledge base about the range of SAI particles that might be used is key to understanding risks. The introduction of sulphates, unlike some of the other proposed techniques, would not create a unique change to atmospheric chemistry because sulphates are continuously introduced into the atmosphere naturally (humans also already add a lot of additional sulphates to the atmosphere). Sources include, for example, meteoric dust, volcanic ejections and emissions from marine, terrestrial, chemical and industrial sources (Keith, 2013). That sulphate interaction within the atmosphere is already occurring and has been researched and, in part, understood, is an important element of the case for choosing sulphates over other particles (Shepherd, 2009, Stilgoe, 2015, English et al., 2013).

The behaviour and interactions in the atmosphere of other possible SRM aerosols are understood in less detail. However, there is existing work on how alumina impacts on the stratosphere following NASA studies motivated by interests in how the Space Shuttle's rocket plume, which included quantities of alumina, might affect ozone (Ross and Sheaffer, 2014). In terms of the terrestrial environment, aluminium oxides are common in natural mineral dusts and this provides an accessible basis from which to research their impacts in detail (Lawrence and Neff, 2009). In addition, there is a broader base of knowledge about alumina from its use as an industrial material (Weisenstein et al., 2015). There is a less well established evidence base for diamond, a material suggested by Keith et al. (2016) for SAI purposes, although there is some evidence that diamond nanoparticles are nontoxic to biological systems (Schrand et al., 2007).

The potential for SAI to lead to ozone loss has been considered one of the most important risks of deploying SAI (Morton, 2015). Ozone is an essential gas layer in the atmosphere, which protects all life on Earth from harmful ultra-violet rays (GES-DISC, 2016). Changes in aerosols in the stratosphere, and in particular the introduction of sulphates, could influence the chemistry, and therefore reduce ozone abundance in the stratosphere (Tilmes and Mills, 2014). This effect was measured after the 1991 Mount Pinatubo eruption (Thomason et al., 2008, Dhomse, 2014), an example of how existing knowledge can inform SAI geoengineering understandings. While the ozone layer is still recovering from the effects of anthropogenic-depleting chlorofluorocarbons (CFCs), studies suggest any new stress on the total ozone column, particularly at high and mid-latitudes before 2050, would lead to a considerable increase in ultra-violet light at the Earth's surface (Heckendorn et al., 2009) and recovery in the Antarctic ozone hole could be delayed by at least 40 years (Tilmes and Mills, 2014).

SAI materials however, may have the potential to increase rather than damage ozone distribution depending upon the particles deployed. Aluminium oxide (alumina) is a solid aerosol which would not, of itself, increase the volume of the aqueous sulfuric acid which drives the reactions in sulphates that lead to ozone loss. However, they do introduce new risks possibly including acting as a catalyst causing reactions that may affect ozone (Keith et al., 2016).

In one of the first SAI related experiments ever to be conducted outside of the laboratory it was announced on 24 March 2017 that Keith and Keutsch plan to test how a range of aerosols would interact with ozone, amongst other experiments (Temple, 2017). The project is funded by Harvard University drawing from a fund of more than $7 million raised from Microsoft co-founder Bill Gates, the Hewlett Foundation, the Alfred P. Sloan Foundation, Harvard's internal funds, and other philanthropists.

It is uncertain how the climate will respond to large-scale forcing. Climate models suggest a theorised ideal compound SRM could be very efficient in reducing model-simulated climate changes (Kravitz et al., 2014, Moreno-Cruz et al., 2012). That gives optimism for future research, but leaves potentially high impact, high cost risks unresolved. Risks that could conceivably include accelerated changes in dynamic transport of moisture and air, affecting weather systems and significantly important local climate phenomena such as monsoon rains and ecosystem functioning (Keith et al., 2016, Mercado et al., 2009). These effects may be disproportionality experienced by those living in the developing world (Moreno-Cruz et al., 2012) and could have important economic and social implications (Stilgoe, 2015).

If a SAI intervention were terminated over a short time period following a period of cooling, it is expected that a significant and very rapid temperature 'bounce back' would result, whilst the climate re-stabilised (Kosgui, 2011). This 'termination shock' would create rapid temperature increases beyond those that would have been experienced had SAI not been undertaken, and would be considerably more damaging. Such a termination shock has the potential for large-scale environmental, economic and social effects (Matthews and Caldeira, 2007). Whilst it is legitimate to suggest, given the scale of impacts, that termination shock is a significant risk, possibly sufficient to rule out SAI, Parker and Irvine (2015) have argued, in a review of potential shock drivers that included terrorism, economic collapse, natural disasters and the unexpected discovery of damaging side effects, that there is no obvious scenario under which rapid termination might in fact take place, given its potential global impact. However, to achieve a state where such shocks do not lead to significant termination shock, serious governance consideration will be required.

SAI would create 'global whitening' of the sky during the day. Creating what Morton (2015) calls a 'veil' over the sky. If, for example, SAI were used to reduced global temperatures to pre-industrial levels, the sky would be between three and five times brighter as well as whiter (Kravitz, 2013) taking on the appearance of clear skies as currently experienced in large-scale urban areas. Perhaps for some, no longer having deep blue skies visible might have profound implications for their well-being. The accompanying soft halo that might appear around the Sun could have similar effects (Ahbe et al., 2015, Leisner, 2017). These changes would certainly affect photosynthetic activity, most likely *increasing* plant productivity.

The use of aerosols may cause harm as they drop out of the stratosphere into the troposphere forming acid rain and air pollution. The resulting number of deaths is uncertain and impossible to estimate accurately, although it is likely to be small compared to current death rates caused by sulphur dioxide air pollution, not least because the 'fall out' would be distributed globally, including over remote unpopulated areas. However, Keith (2013) argues that the death rate would be markedly less than the number anthropogenic climate change related deaths that would be avoided through the SAI. Effiong and Neitzel (2016) argue that possible health effects are insufficiently understood and that further SAI research should include health cost benefit analysis and work on methods of assessment of exposure to, and evaluation of, the toxicological properties of potential sulphates and other materials.

2.6 Summary

Table 2.4, which summarises the key strengths, weaknesses and risks of SAI suggests that, whilst more basic science research and engineering is required, SAI is probably currently the most feasible high impact geoengineering option available. Much of the fundamental technology is pre-existing - sulphate manufacturing is well understood and practiced, and aircraft for delivery are well known technologies. It can be expected to be highly efficient and cost effective, and because SAI replicates existing atmospheric processes seen during volcanic eruptions, the behaviour of which have been studied observationally, it is possible to have some understanding of how SAI might affect the atmosphere and planet. (Long et al., 2011).

Table 2.4 The key strengths, weaknesses and risks of stratospheric aerosol injection solar radiation management

STRENGTHS	WEAKNESSES	RISKS
High potential for effectiveness, capable of delivering planetary cooling within one year (Keith, 2013).	The detail of delivery mechanisms are yet to be finalised. However, aircraft are thought capable of deploying at scale (Morton, 2015).	A potential for damaging shifts in rainfall patterns. (Robock et al., 2009).
The cost of SAI, compared to other geoengineering measures, is low. Cancelling the effects of a doubling of GHG concentrations would cost circa £25-50 billion (Crutzen, 2006a).	Currently no appropriate governance tools are available for a technology with planetary scale effects (Shepherd, 2012b).	Sulphates have capacity to reduce atmospheric ozone (Keith, 2013).
The functioning of aerosols in the atmosphere is understood from studies of volcanic eruptions (Long et al., 2011).	Ocean acidification would continue unabated if SAI substituted climate change adaptation and mitigation measures (Wallace et al., 2010).	Potential for large scale migration following shifts in weather patterns (Robock et al., 2009).
A restructuring of global energy supply systems would not be required (Keith, 2013).	Global whitening of the sky may have psychological consequences (Ahbe et al., 2015).	Climate termination shock following abrupt termination of SAI deployment could be significant (Kosgui, 2011).
Potential for accelerated plant growth and food production (Morton, 2015).		

The potential environmental impacts that might arise from uncertainties associated with the introduction of SAI are novel. Key uncertainties relate to how the earth system (climate, oceans, weather, agriculture, water cycle etc.) may respond to SAI (NERC, 2011). It is unclear, for example, if SAI might lead to adverse effects on regional hydrologic cycles, stratospheric ozone, high-altitude troposphere clouds, ozone and biological productivity (Shepherd, 2009) nor what the human, social and economic knock-on effects of these might be. Further, the potential for a termination shock also raises import issues (Kosgui, 2011). SAI is also expected to have regional and local effects in locations remote from implementation - regional climate variation with drying in some places and wetting in others, better crops in some and worse in others, and reduced moisture in tropical soils (Robock, 2008). Global whitening of the sky during the day would be a further environmental effect. Each of these risks or combinations of risks has the capacity for high impacts, both within and across boundaries, raising important governance questions. The governance issues associated with SSI are now explored in Chapter 3.

CHAPTER 3 - STRATOSPHERIC AEROSOL INJECTION SOLAR RADIATION MANAGEMENT (SAI) GOVERNANCE

3.0 Chapter overview

This chapter defines governance and reviews the governance issues raised by SAI. Drawing from law, political science, geography, and science and technology studies literature a range of governance issues are explored including the scale of SAI's effect, geopolitics, the nature of the technology as a tool to change the Earth system intentionally and its social and political appraisal. The role of scientists in governance debate is reviewed, with particular attention to the important Stratospheric Particle Injection for Climate Engineering (SPICE) Research Project.

3.1 Governance

Governance is a widely used term and can mean different things to different people. This definitional difficulty is a key characteristic of governance scholarship, yet without careful definition governance research lacks focus (Schneider, 2004). Chhotray and Stoker's (2009, p.3) definition is used in this study, i.e., that *'governance is about the rules of collective decision-making in settings where there are a plurality of actors and organisations and where no formal control system can dictate the terms of the relationships between these actors and organisations'*. An analysis of governance and risk in Chapter 4 provides the thesis' theoretical framework of governance and risk and suggests how the SAI governance issues identified in this chapter might be addressed.

Dilling and Hauser (2013) reviewed the key drivers for geoengineering governance, identifying:

- the lack of appropriate existing governance mechanisms and regulation tools;
- scientists' debates about governance and the nature of the science;

- risk, ethical issues and uncertainties about the technologies and their potential impacts on both the environment and society;
- questions of politics and power; and,
- the need for transparent decision making.

These are reviewed in the context of the SAI risks discussed in Chapter 2 and summarised in Table 3.1.

Table 3.1 SAI deployment risks

PROBABILITY OF OCCURRENCE	POTENTIAL RISK
Low	Significant, unpredicted temperature reduction. Potential for destructive military use.
Uncertain	Diminished climate change mitigation – unabated GHG emissions effects on ecosystems, oceans and global energy supply. Financial loss and cost, e.g. changes in food production, drought and flooding. Effects on regional climate. Political instability affecting balance of power in any thermostat-setting decision-making process. Increased rate of extreme events. Bounce back damage following abrupt termination. Human error – design, manufacture and operating failures. Ozone depletion - increased ultra-violet flux to Earth's surface. Unexpected impacts and implications 'unknown unknowns'. Large-scale human migration/SAI refugees. Global whitening - 'no more blue skies'. Continued ocean acidification (without climate change adaptation). Sulphate or other particle fallout related deaths and other environmental effects. Changes in plant photosynthesis capacity – unknown rate of change and effects. Enhanced acid rain potentially exceeding biological thresholds. Financial opportunity costs.
Known will occur	Reduced sunlight reduces solar power output.

3.2 Legal instruments

However difficult fixing a definition of governance may be, the approach does share some characteristics with international law as a fragmented, poly-centric and cross-cutting system of norms, rules and institutions (Gowlland-Debbas, 2010). Indeed, in the context of new technology appraisal, and adoption, governance has been described as the intersection between power, politics, and institutions, including legal institutions and instruments (Leach and Stirling, 2010). Law and regulations, then, play an important role as part of the wider governance mix (Scott and de Burca, 2006).

Currently, there is no jurisdiction or treaty with a sufficiently broad coverage to address all aspects of SAI regulation (Redgwell, 2011, Armeni and Redgwell, 2015). Neither is it likely that a single treaty dedicated to SAI is warranted or appropriate. Armeni and Redgwell (2015) argue that it is unclear whether it would be more appropriate to develop a set of international legal instruments, or whether other local, regional or national instruments may be more appropriate for the regulation and governance of SAI. Ostrom (1999), for example, has argued that it is more effective to manage commons, including the global commons, at the level of the local rather than international. Therefore, whilst a formalistic review of regulatory mechanisms to establish whether sufficient are in place is required, in order to ensure the current governance landscape is understood, the exercise may be more useful as an indicator of the scope of the challenges SAI poses for international law.

Neither the 1992 UNFCCC nor the 1997 Kyoto Protocol (UN, 1992, UN, 1998) include any explicit reference to geoengineering. They do however establish a significant institutional structure for international governance of the climate regime, creating a space for mutually supportive activities. This suggests the protocols may be able to help foster linkages and develop common approaches in relation to geoengineering and SAI.

The 1992 Convention on Biological Diversity (CBD), with 168 signatories, has three main goals:

- to conserve biological diversity;
- the sustainable use of biodiversity, and,
- the fair and equitable sharing of benefits arising from genetic resources.

The CBD is one of the few conventions to have discussed geoengineering directly (although not SAI specifically). The initial focus was on ocean fertilisation activities and requested signatories not to *'undertake ocean fertilisation until an adequate scientific basis on which to justify such activities and a global transparent and effective control and regulatory mechanism was in place'* (CBD, 2008, p.7). In 2010, with a view to protecting biodiversity, the CBD went further, in accordance with the Precautionary Principle, and called on parties not to *'undertake climate related geo-engineering activities until there is an adequate scientific basis on which to justify them and appropriate consideration of associated risks to the environment and biodiversity and associated social economic and cultural impacts'* (CBD, 2010, p.5). It should be noted however that the CBD recommendation did not include small-scale scientific research studies undertaken in controlled settings that would help identify the potential impacts on the environment.

Whilst the CBD position appears strong, it is not legally binding. The language used is 'soft', only inviting parties rather than requiring parties to comply and it only extends under the CBD's mandate in relation to the conservation of biodiversity and the sustainable use of biological resources. The CBD evocation of the Precautionary Principle may, however, be an important demonstration of international law's willingness to take such measures in time. However, the limitations of the CBD also highlight that individual extant protocols and conventions as currently constructed could only form an incomplete basis for global regulation given they each apply to discrete, specific topics and issues whereas SAI operates, as noted above, at scale, across treaty boundaries.

Currently, there are three other international agreements that may be applicable to

SAI and its effects. The 1985 Vienna Convention on the Protection of the Ozone Layer (UNEP, 1985) and the 1987 Montréal Protocol (UNEP, 1987), which both have 196 signatories, aim to protect against depletion of the ozone layer. Given that the injection of aerosols and, in particular, sulphates may harm atmospheric ozone they may both be applicable to SAI. However, it is at this stage unclear to what extent the ozone layer might be damaged by SAI, hence the scope of their applicability to SAI is also unclear.

The 1977 Environmental Modification Convention (ENMOD) (UN, 1977), formally the 1976 Convention on the Prohibition of Military and Other Hostile Use of Environmental Modification Techniques, prohibits the intentional use of environmental modification by one-party against another for hostile purposes, and completely bans the use of weather warfare, activities which have previously been undertaken by the United States of America during the Vietnam War (Hersh, 1972). ENMOD is not expected to be applicable to SAI given it is unlikely to be used as a military weapon in the first instance; although SAI may have the potential to be used as such. Secondly, the Convention has limited reach - having been signed by 73 countries, leaving many non-signatory countries free to act.

The Convention on Long-Range Trans Boundary Air Pollution (CLRTBAP, 1979) entered into force in 1983. It is implemented by the European Monitoring and Evaluation Programme, under the direction of the UN Economic Commission for Europe. The Convention covers 22 pollutants, the majority of which are pesticides and insecticides. Currently there are 51 signatories and as such the convention suffers from the same coverage problem as ENMOD. In addition, sulphates and other possible SAI aerosol particles are not listed as a prohibited pollutant. Further, the Convention defines trans-boundary air pollution as '*air pollution whose physical origin is situated wholly or in part within the area under the national jurisdiction of one state and which has adverse effects in the area under the jurisdiction of another state at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources.'* (CLRTBAP, 1979, p.2). Given that if SAI were deployed it would be possible to identify the sources of the aerosol (although it should be recognised that this could be a complex task) the Convention would, as drafted, be difficult to apply. Given the Convention is aimed at protecting against pollutants, this creates a paradox in that SAI may or may not be considered a pollutant in the context of its function of mitigating the effects of anthropogenic greenhouse gases, in themselves considered as pollutants, although not listed in the Convention.

There is, then, no treaty readily available, or easily adaptable, for application to SAI. Nor, it is argued (Armeni and Redgwell, 2015), should one be constructed, as to seek to regulate SAI by a single existing instrument at the expense of a more flexible governance ‘patchwork quilt’ would be an error as the competence and expertise embedded in extant instruments could better regulate SAI. They, however, recognised that the success of such an approach would be contingent on the institutional responses being highly interconnected and co-ordinated. An important challenge to this ‘Patchwork quilt’ model would be to ensure international institutional frameworks engage with local and cross-national co-management arrangements (Armeni and Redgwell, 2015).

A key opportunity might be to build on extant local ecological knowledge and governance structures that have evolved over long timeframes through the processes of social learning and to incorporate these into wider international governance approaches (Morton, 2015). However, such approaches may undermine the effectiveness of regional and local ecosystem governance structures through the imposition of top-down regulations, that could be underpinned by a poor understanding of local social and ecological contexts (Ostrom, 2010).

3.3 Science and governance

Scientists have recognised the need for SAI governance in the context of the evidence, albeit limited, of negative public perceptions about SAI (Macnaghten and Szerszynski, 2013, Pidgeon et al., 2012). There is also recognition by some SAI researchers that they are in danger of either lacking, or being perceived to be lacking, humility as they work toward developing the means to control the climate, an ambition that Keith (2013) has recognised touches on hubris. It has been suggested that researcher awareness of the governance failings associated with other controversial research fields such as nanotechnology and synthetic biology may have informed this perspective, alongside the public's responses to early SAI research activity (Sarewitz, 2010).

The Stratospheric Particle Injection for Climate Engineering Research Project (SPICE) is a good example of unexpected public responses to SAI and the uncertainty and complexity of SAI science governance. SPICE was an Engineering and Physical Sciences Research Council (EPSRC), Natural Environment Research Council (NERC), and Science and Technology Facilities Council (STFC) co-funded 3½ year collaboration between the Universities of Bristol, Cambridge, Oxford and Edinburgh. It began in October 2010, in response to the Royal Society report that had encouraged the Research Councils and others to fund research into geoengineering (Shepherd, 2009).

The SPICE project had three strands: (i) to better understand the optical and chemical characteristics of candidate particles through lab based experimentation and observation, (ii) to conduct environmental and climate modelling of the effects of a chosen particle, and (iii) to explore through a test-bed a potential delivery system. The latter planned to test a one-twentieth scale delivery system that would have comprised a 1 kilometre high hose supported by a tethered balloon which would spray 150 litres of water, not an aerosol (Watson, 2010). Whilst the test-bed was then not seeking to undertake SAI, even at a very small scale, it was highly symbolic as the UK's first planned field trial of a geoengineering SAI technology.

The announcement of the project, and in particular the test-bed, was widely reported in the media, for example on radio and in the press (Cooper, 2011, Ruz, 2011, Monbiot, 2011, Daily Mail, 2011). On 29 September, two weeks after the research award announcement the test-bed was delayed for six months to allow for further engagement with stakeholders following the reporting of the study and a series of protests from NGOs including Friends of the Earth and the Action Group on Erosion, Technology and Concentration (ETC) about its governance. On the day of the announcement to delay the project a petition (ETC, 2011) signed by more than 50 organisations was presented to the Secretary of State for Energy and Climate Change, Chris Huhne, MP and the EPSRC. This open letter called for a suspension of the project in the light of concerns about SAI's governance, and in particular a possible conflict of interest with the CBD, the UN Framework Convention on Climate Change and the UN Conference on Sustainable Development. Following consultation with Professor Philip Macnaghten, Chair of an independent stage-gate panel which required some reflexivity and deliberation on the context surrounding the project as well as more traditional risk identification, management and regulation compliance, the funders took the decision to further delay the test-bed to allow the project team to undertake wider engagement work (Macnaghten and Owen, 2011).

Further discussions between Research Councils UK (RCUK) and the SPICE team led to the eventual complete withdrawal of the experiment in May 2012. This decision was made, according to the SPICE project website (Watson, 2012), because of issues of governance and intellectual property. Stilgoe (2015), however, suggests the decision reflected an insufficiency of time to undertake adequate stakeholder engagement prior to any activities.

The tendency for researchers to argue that they have no plans to implement SAI and simply want to research its potential has played an important role in encouraging the formation of what might be a false boundary, with research and its governance being separated from any future deployment and its governance (Parson and Kieth, 2013). Much of the debate to-date has focussed on research governance, only referencing in passing the implications for application governance, arguably delaying the development of good governance practices through learning by doing (Dilling and Hauser, 2013, Parker, 2014).

Given the low likelihood of creating environmental or social risks, laboratory-based research might be expected to be governed through normal research protocols. However, scale field trials would eventually necessarily deliver a perturbation of the climate on a larger scale, in effect an application of SAI that might lead to uncertain, difficult to predict effects and risks (Robock et al., 2009). The problem of locating and understanding where the research/application governance boundary lies brings into question whether there should be any delineation between the two, or whether the evolution of the technology from modelling and laboratory research through to atmospheric testing at scale should be treated as a continuum for governance purposes (SRMGI, 2011, Parker, 2014). If the demarcation question is to be resolved, some form of a universally agreed metric that identifies a point at which research becomes implementation will be required. What this tool might be may be difficult to resolve. Parsons and Keith (2013) have suggested that a measurement of the cooling effect in watts per square meter of field work would be appropriate. Other measures, such as some form of metric of social response, have also been proposed (Sugiyama et al., 2017).

Egede-Nissen (2010) highlights the role of scientists as actors with vested interests when analysing scientists as gatekeepers of knowledge. The suggestion that scientists recognise their role in 'good governance' of SAI is reflected in reviews of their behaviour around SAI. Oldham et al (2014), for example, analysed the publication behaviour of scientists using bibliometrics and suggested they are seeking to contribute to democratic deliberation on the governance of climate engineering in general by explicitly seeking to make visible emerging patterns and structure in scientific research and patent activity.

In addition to scientists who are proactively engaged in SAI basic and applied research, a wider constituency of actors is increasingly clustering around SAI. Special interests, including private corporations, conservative think tanks and scientists affiliated with both, are already drawing on a variety of discursive frames to limit, shape and mould the current debate surrounding SAI and its governance to their interests (Sikka, 2012). More specifically Kintisch (2010) identifies a 'geoclique' that he suggests initially formed around two key US scientists, David Keith and Ken Caldeira, and which Hamilton (2013) suggests is now developing around a network of individuals with personal, institutional and financial links. The latter include a number of billionaires such as Bill Gates and Richard Branson, which suggests the burgeoning commercial engagement in geoengineering research is aware of and engaged in affecting the governance debate at an early stage in its development.

3.4 Cross boundary and scale issues

Questions of scale are critical. Although SAI could be operationally contained within a nation state, the effects of SAI activities will always be global and affect the global commons. Traditional notions of, and approaches to, environmental and global commons governance do not operate at the system level of human interaction (Ostrom, 1999). Thus, SAI would create a governance vacuum, requiring new governance solutions. A governance arena that would be complicated by risk and uncertainty within the science (Evans, 2012) and ambiguity about the adverse effects of SAI on, for example, regional hydrologic cycles, temperature and climate, stratospheric ozone, high-altitude troposphere clouds, ozone, biological productivity and food production as discussed in Chapter 2, section 2.5 (Solomon, 1999, Gu, 2003, Shepherd, 2009).

The combination of uncertainty, scale and intentionality opens up important governance questions. Could, for example, globally effective international, transparent and accountable governance systems evolve and be open to public security, where all actors are able to participate freely in a democratic manner, with the full participation of civil society (Macnaghten and Owen, 2011)? Might rigid regimes be required, or will interested and affected parties act independently of any global governance measures (Morton, 2015)? Critically, the use of SAI would mean, for the first time ever, that humans would have taken a conscious and intentional choice to change the planetary system - which would come with a unique set of associated philosophical, ethical and moral questions (Morrow, 2014).

Regional climate variation with drying in some places and wetting in others, better crops in some and worse in others, and reduced moisture in tropical soils are all potential risks of SAI that could affect common pool resource wellbeing (Robock, 2008). Local governance and knowledge capacity within these commons is generally well developed and understood (Ostrom, 1999). However, SAI will create new direct causal linkages across scales conjoining governance agenda for global commons in new ways. How these are navigated will expose new insights into governance processes. Will, for example, local common pool resources governance actors engage to construct new macro global commons governance and reshape local, established commons governance? Alternatively, regional and local ecosystem governance structures could be disturbed through the imposition of top-down regulations, underpinned by a poor understanding of local social and ecological contexts (Ostrom, 2010).

There are important questions about what 'large-scale deployment' might mean. Bellamy et al. (2012) demonstrated that initial SAI literature focussed on interventions designed to cool the planet to pre-industrial temperatures. However, increasingly it is suggested that SAI might be used as a contribution to human efforts to reduce the effects of climate change (Morton, 2015, Keith, 2013) as part of a suite of mitigation and adaptation measures. McClellan and Keith (2012) argued that SAI interventions might better aim to cut global warming by half or less over an extended time frame using a smaller volume of aerosols with fewer potential side effects and, crucially, a lower level of risk from 'termination shock'. The governance process that leads to any decisions about the level of deployment will then be critical in light of the uncertainty entailed with a move from the laboratory to the environment (Parker, 2014).

Although SAI is capable of being territorially contained, in that it can be operated from a specific site, the effects of SAI activities will always be global. For example, if China were to control radiative forcing regionally over the Pacific Ocean with a view to generating more precipitation over China, that might have significant effects on the Indian sub-continent Monsoon, raising important governance security questions (Keith, 2013). This scale is important not only because traditional notions of governance do not operate at the level of human interaction with the planetary system.

The combination of scale and intentionality then opens up a wide range of governance challenges, not least how appropriate governance might be constructed or adapted from existing models and what role science might play in informing it. Some key questions flagged in the literature that remain unanswered include how could, or should, a global consensus backed by multiple governments, international organisations, NGOs, environmental and critical groups and others be arrived at (Macnaghten and Owen, 2011). Further, how might, and should, global, transparent, and accountable governance systems, where all actors are able to freely participate in a democratic manner, with full participation of civil society, be operationalised in the context of the planetary scale (Bellamy et al., 2012). Coupled with these challenges may be other concomitant large-scale international governance challenges that could be perturbed or exacerbated by SAI, such as the governance of hunger, poverty, loss of biological diversity, ecosystem degradation, and ocean acidification (Stilgoe, 2015).

3.5 Intentionality

A key issue in the SAI and wider geoengineering governance literature has been its uniqueness as an intentional intervention into the Earth system (Kreuter, 2015). Humanity has progressively changed the chemistry of the atmosphere and oceans, the hydrological cycle and the albedo of the land surface over millennia and in particular since the great technological advancement from the 1950s (Goudie, 2013). Agriculture, urbanisation and industrialisation have all played a part in this process. A key characteristic that sets aside SAI from these is the 'intentionality' associated with its use. For the first time SAI would mean humans would be making a conscious choice directly and knowingly to change the planetary system (Macnaghten, 2010). This raises multiple risk and uncertainty issues, including philosophical questions about the nature of intention and harm, which give rise to governance questions novel to SAI (Morrow and Svoboda, 2016).

The release of anthropogenic greenhouse gases is currently undertaken in the knowledge of their effect on the climate, and therefore with an intent to heat the planet. However, the intentional heating of the planet through the release of GHG is a by-product of actions undertaken for other purposes, for example, the generation of heat and power. SAI, on the other hand, would be undertaken with the direct intent of affecting the climate and therefore comes with a different set of associated governance questions that may need addressing from a philosophical perspective (Curvelo, 2014).

3.6 SAI in the context of the Anthropocene

The adoption of the epoch term, the Anthropocene, is in recognition of humanity becoming the biggest driver of change in the Earth system. It suggests that the influence of humankind on our planet's systems had become so pervasive and fundamental as to usher in a new geological era (Crutzen and Stoermer, 2000, Steffen et al., 2007). In August 2016, the International Geological Congress, the recognised epoch naming authority unanimously accepted this proposition by voting for the transition to be officially registered (AFP, 2016). This raises novel questions about humanity's planetary management responsibilities and these chime with similar planetary scale management issues raised by SAI (Baskin, 2015, Rayner and Heyward, 2013). These are briefly discussed below and lessons learnt from the research findings, that inform the wider Anthropocene debate are explored in the discussion chapter (Chapter 9).

The Anthropocene describes how human activity is having overwhelming biophysical effects on the planet as a whole (Crutzen and Stoermer, 2000).

It is claimed that humans:

- manage three quarters of all land, excluding the ice sheets;

- use half of all fresh water on Earth;
- have created the highest levels of GHG in over a million years;
- have created a hole in the atmospheric ozone layer;
- fix more Nitrogen than all natural processes; and,
- are causing many of the world's deltas to sink due to damming and mining.

Human engineering has become so large scale that individual projects are having a global effect, for example, the angular momentum of the water restrained by the Three Gorges Dam has shifted Earth's axis by 0.8 of an inch and slowed the Earth's rotation (Gross and Chao, 2006). Humanity has even created a new form of rock, having made in the order of 500 billion tonnes of concrete since 1930 (Waters and Zalasiewicz, 2017), sufficient to place one kilogram of the material on every square meter of the Earth's surface – land and sea (Zalasiewicz et al., 2011).

This new state gives rise to governance and technocratic questions about risk management, equality, stewardship, control and responsibility at the planetary scale in similar ways to SAI in relation to the atmosphere, climate and the acidification of the oceans. For example, it raises questions about:

- who governs what and with what authority;
- how uncertainty and risk are incorporated into planetary governance; and,
- the role of scientists in the governance and risk management processes.

Other similar questions include whether democracy is an important principle and who will be responsible for harm or loss that may result from any decisions taken.

As with SAI, there are contested views about how humanity's response to the Anthropocene might be manged (Baskin, 2015). For example, some suggest SAI should be used directly as it is available (Lynas, 2011), after what they see as failures to adapt and mitigate. Whilst, in the context of the Anthropocene, Steffen et al. (2007) argue humanity should do whatever it takes, by adopting new technologies such as SAI, as soon as possible to ensure humanity survives. This is translated into a populist narrative by Lynas (2011, p.8) who notes "Nature no longer runs the

Earth. We do." and calls for a new regime of active planetary management that would explicitly include SAI.

Some take a more cautious view, such as Baskin (2015), who suggests that whilst arguments that humanity may be 'post-nature' and that the Earth is, literally, socially-constructed may be premature, they require examination and might already justify the use of SAI. Whilst, Ellis and Haff (2009) see a managerial role for science, calling for it to take responsibility, demanding that scientists commit to a 'post natural' science paradigm. Even claiming that Earth scientists should take an oath to be more influential in guiding the public and decision makers toward more successful management of human systems, which they see as the only Earth systems that truly pose a serious threat to the future of humanity.

The Anthropocene is, then, taken by some (Rockstrom et al., 2009) to mandate a new role for scientific experts in a technocratic future. That is that they should tell policy makers when humanity or the Earth System is in danger and guide policy-making to protect against catastrophe (Lynas, 2011). Science would, in this model, be the authority that both defines and monitors the 'safe operating space for humanity' (Rockstrom, 2011), and would police infringements on humanity's behalf. Such an ideology is in marked contrast to widely accepted more nuanced understandings of the relationship between science, society and governance, which recognise that narrow, expert, science-based approaches are only part of a plural process (Stirling and Mayer, 2001, Jasanoff, 1994, Renn, 1998). This view recognises the complexities in the characterising, prioritising and distribution of risks, their cultural and ethical implications, and that how they are communicated and interpreted transcends the narrow scientific notions of social assessment which would be on offer from scientists alone (Slovic, 1993, Otway and Wynne, 1989).

Rockstrom (2009) suggests planetary boundaries, defined by scientists, would identify where the 'safe operating space' is situated and that the boundaries would then be used as a governance tool. A science-based organisation or group, he suggests, would set limits on consumption and construct mechanisms to calculate aggregate use and allocate 'shares'. Any nation, region or global organisations that subsequently used more than their 'fair share' would be subjected to some form of punishment. How these mechanisms would operate and what punishments might be levied is unexplained. However, it is clear that it would require some form of governing technocracy comprised of expert scientists who would identify and set boundaries for others to achieve or comply with, and presumably act as police officer, if not enforcer.

Such prescriptive responses to the Anthropocene expose it as not only a scientific concept, but also a world-view 'ideology'. This ideology would legitimise action for scientists in a 'land grab' for influence. It would give rise to important questions about democracy, in ways similar to those flagged in relation to SAI. As Leach (2013) notes, the role given to scientific experts in identifying planetary boundaries or 'non-negotiable natural limits', coupled with ideas about the nature of scientific authority and evidence as incontrovertible and closing down uncertainty, would create an inappropriate role for science in determining pathways and courses of action. Understanding whether such responsibilities might be given to science and scientists in relation to SAI is not a key objective of this study. However, the findings do shed light on these issues, and they are therefore considered in the thesis discussion.

3.7 Socio-ethics

While we know climate change is occurring, and that SAI may provide a solution to mitigate its effects, we may, or may not, choose to adopt it. SAI would then give rise to a theoretically contested, but practically universal moral principle that it is worse to bring about a negative or bad outcome deliberately than to allow it to happen (Gardiner, 2013). The question then is whether SAI would bring about negative outcomes, where SAI counts as 'doing' whereas failing to impose effective mitigation policies counts as 'allowing' (Curvelo, 2014).

SAI also raises intergenerational ethical questions. Should we, for example, act for the benefit of unknown future generations or continue to act in our own self-interest, which may mean that we choose not to develop SAI or other geoengineering technologies in favour of continuing on our current path? Both in an intergenerational but also a current world sense ethical consent is also unclear. Who should or could give consent and under what jurisdiction might that power be exercised? This is particularly important in the context of the global commons and sovereign states but also raises questions about democratic plurality, both at the nation and international level.

Moral hazard - i.e., the risk that geoengineering interventions might undermine or threaten the enthusiasm for further climate change mitigation efforts - also requires attention (Corner and Pidgeon, 2010). Although, in the case of SAI, it has been suggested that even simply considering and debating the potential use of SAI could have the opposite effect and help galvanise mitigation efforts (NERC, 2011). An alternative view suggests SAI might lead to risk compensation and actors adopting more dangerous behaviours, i.e., emitting more GHGs than prior to deployment. An analogy being that evidence suggests that motor vehicle drivers are 40% more likely to drive close to cyclists who wear helmets than those who don't (Keith, 2013).

It is suggested that it might be most appropriate to develop SAI as a last resort technology, an emergency downstream measure in the face of catastrophic global warming events such as drought, food or crop failure (Victor et al., 2009b). Should such an approach be adopted, then there is a question as to whether this would provide justification for not thinking about the downstream consequences of current GHG emissions, on the basis that an ethical approach has been taken to construct an emergency intervention tool available to future generations (Victor et al., 2009b)?

3.8 Geopolitics

Geoengineering, whether it be SAI or another approach, has the potential to alter the geopolitics of climate change (Morton, 2015). Extant international institutions engaged in the politics of climate change are currently unlikely to be in a position to respond in meaningful or constructive ways to SAI implementation (Armeni and Redgwell, 2015). Any international institutional discussions of SAI, at the United Nations for example, may even have disruptive effects on the already challenging and ambitious goal of delivering the global mitigation and adaptation strategy set out in the Paris Agreement (UNFCCC, 2015). A governance debate about SAI would necessitate consideration of what an optimal global climate might be and what an appropriate governance model might look like (i.e., global treaty or polycentric arrangements). Achieving a consensus in relation to climate change adaptation and mitigation would become an even more challenging task than it currently is.

At the level of the nation state, SAI raises questions about sovereignty and whether and how nation states might either be forced to, or decide to, relinquish sovereign rights over their air space which could be affected by the injection of aerosols anywhere around the planet. This is complicated by the controversial question regarding the boundary between national airspace and outer space, which remains undetermined in International Law (Cheng, 1997). It is unclear, for example, to what extent nation states might have rights or jurisdiction over aerosols that pass through or affect their air space, and even what having such jurisdiction might mean in practice for the use of SAI and the state.

It has been suggested that SAI is a potential driver of transboundary conflicts, and war, through global, regional, national and local scale effects exacerbating existing climate change contestations, for example, over access to water resources (Brzoska et al., 2012). Such a 'nudge' risk is greater because of the perceptions of possible SAI affects, their uncertainty, and because they could be quick, severe, and heterogeneous with the likelihood of having regional variability. However, a more technologically optimistic perspective argues that SAI has the capacity to reduce climate-related conflict (Mass and Scheffran, 2012). Whilst uncertainty about the risks of SAI remain, the potential for conflict responses to its use are likely to be unresolved (Link et al., 2013).

In the context of nation states' interactions in any decisions to deploy SAI, conflicting logics will be at play (Wiertz, 2012). For example, states already have contested world-views about global warming governance. Some, such as the Russian Federation, may see some benefit from warming whilst others, such as geographically low-lying states may face existential threats from sea-level rise (Schellnhuber, 2011). SAI introduces a new complexity into this game of 'global thermostat tinkering' where availability might persuade some to increase greenhouse gas emissions in response to what they may see as overcompensating SAI. From an economics governance perspective geoengineering does not necessarily increase the free-riding effect on mitigation (Moreno-Cruz et al., 2012).

3.9 Publics and social appraisal

The strong and often divided positions that SAI has prompted amongst publics (Corner and Pidgeon, 2010), the recommendations arising from the UK Natural Environment Research Council's public dialogues (NERC, 2011), and other calls for public dialogue (Shepherd, 2009, Gardiner, 2010) suggest SAI is perceived to be less publicly acceptable than other geoengineering approaches. Given the uncertainty, value loading, and a plurality of legitimate perspectives that surround SAI it might best be described as a 'post normal science' (Funtowicz and Ravetz, 1993, Gibbons, 1999). This framing provides a way of thinking about the technology that could usefully inform the construction of its governance, a framework that would demand an inclusive, transparent dialogue between scientists, publics and their institutions as SAI evolves from the lab to application and beyond (Victor et al., 2009b, Blackstock and Long, 2010).

Engagement regarding SAI to date suggests publics are sceptical. However, what they are sceptical about remains unresolved (Cairns, 2014b). The publics' judgements may be responses to the potential perceived effects of the technology, responses constructed in part by perceptions of climate change and the need (or not) to adapt. They could be reflections of how people perceive dominant scientific and policy institutions and their behaviours, including their representations of the public themselves (Wynne, 1989) or the capability of institutions to govern the technology (Morton, 2015). More public engagement will then be important to inform, legitimise and allow for transparent SAI governance decision making (Macnaghten and Szerszynski, 2013). However, this dialogue may be difficult to progress given the power relations that currently underpin SAI research decision making processes (BPC, 2011). The technical uncertainty and ambiguity that surround SAI could, effectively, be discouraging dialogue, with only a small number of informed or highly motivated actors having the necessary expertise or capacity to engage, reinforcing the idea of the 'geoclique' (discussed in section 3.4) (Lovbrand, 2007).

3.10 Conclusion

A nascent literature emerging from several disciplines has recognised and discussed the governance challenges posed by SAI both in terms of governing the technology and its use, as well as how the risks associated with its development and deployment might be governed. Many of the governance issues discussed are free standing and lack a coherent theoretical framing. The next chapter seeks to develop a framework to help address the governance challenges.

CHAPTER 4 - THEORETICAL FRAMEWORK OF GOVERNANCE AND RISK

4.0 Chapter overview

This chapter provides an overview of my theoretical interpretation of risk and how the governance of SAI might operate. It constructs a conceptual framework of governance which suggest how decision-making about SAI might be enacted. The key concepts of consent, consensus and concord are introduced, and how these may play out in the governance of the technology is explored.

Risk is charaterised, and how it might be interpreted, responded to and incorporated through governance is theorised. The Precautionary Principle is explored in relation to SAI and a model that locates the technology in a risk management typology, which suggests how SAI governance might be opened up beyond a precautionary approach, is discussed. SAI is then fitted to this model and what this means for its risk management and governance discussed.

4.1 Meanings of 'governance'

As stated in Chapter 3, section 3.1, this study uses Chhotray and Stoker's (2009, p.3) definition that *'governance is about the rules of collective decision-making in settings where there are a plurality of actors and organisations and where no formal control system can dictate the terms of the relationships between these actors and organisations'*. Decision-making refers to making choices about alternative actions available, but, importantly, relates to actions at different scales. Decisions can then be about both strategic direction and policy, or discrete day-to-day activities. They can be taken collectively on behalf of whole societies, or in micro governance environments within, for example, small organisations.

Key to understanding decision-making and governance is the identification of who takes decisions for whom, under what authority and how that is given, or allowed to be taken. Collective decisions are made by groupings of individuals and involve issues of mutual influence and control. They generally involve rights for some to have a say, but require that all collectively accept the decisions. Rules refer to those in use rather than rigid understandings of rules; that is to say both the formal and informal ways people determine what to decide, how to decide, and who should decide. Finally, the absence of formal control indicates there is no person or body 'in charge'.

Governance is not static. Chhotray and Stoker (2009) argue there have been two headline drivers of governance over the past twenty years: globalisation and democratisation. In this context globalisation can be thought of as the spread of global economic and social links, but also the increasing capacity to act and affect change on a global scale. Democratisation reflects the changing expectations of citizens about their capacity to influence decisions that affect them. Other drivers include changes in the economic, political, social, scientific, technological and ecological contexts that place new demands on existing arrangements. Governance, then, is an organic process within which paradoxes can arise where drivers are both external and internal to the governance process, and SAI would clearly fit this framing.

4.2 The research model of SAI governance

Spatial, scalar representations of nation states operating within a hierarchical, nested 'Russian Doll' model are not able to capture the 'on the ground' empirical reality of contemporary global environmental governance (Bulkeley and Newell, 2010). Anthropogenic climate and earth systems change are changing conceptions of where environmental governance takes place, shifting the focus from regimes to causal actors. Scholars can no longer neglect considerations of where the most important decisions affecting the environment are made, whether they be local, regional or national or within organisations or communities of interest. Thus, regime models are increasingly being replaced with an analysis that recognises a 'messy' mosaic of unevenly superimposed and inter-layered actors (Brenner, 2001).

Such a perspective aligns well with the generic definition of governance introduced in the previous chapter (section 3.1) and one that offers a more open approach that can incorporate multiple actors who play roles in the construction of various knowledges. However, a conceptual framework of SAI governance must not only incorporate this 'messy' polycentricism, but also offer a theoretical insight into how decision-making might be enacted, of how authority is negotiated, taken and given. In other words it needs to understand the 'machinery' of governance.

There is increasing interest in the environmental governance literature about how a better understanding of simultaneous actions, across multiple scales, by multiple actors and institutions can be arrived at (Jacobson, 2000, Newell, 2000). Three concepts of such non-national or 'transnational' governance of the global environment have evolved:

- epistemic communities (Haas, 1990);
- transnational advocacy coalitions (Keck and Sikkink, 1998); and,
- global civic society (Lipschutz, 1996).

Epistemic communities comprise informed networks of experts with deep understanding of the scientific character of a technology that will impact on the environment, an environmental problem or interrelated problems (Haas, 1990). However, this perspective fails to incorporate the influence of risk, uncertainty, and ambiguity amongst both scientists *and* other interested or affected parties, and how these might influence the uptake and governance of technologies that affect the global environment (Wynne, 2001, Zhang et al., 2011).

Transnational advocacy coalition analysis accepts the role of the state, but rejects hierarchical understandings of the state's place within global environmental governance, recognising the presence of horizontal networks across states as well (Keck and Sikkink, 1998). The third concept, global civic society, rejects the location of authority within the state and locates political authority in networks that lie outside.

Unfortunately, all of these approaches fail to address fully the challenge of understanding the complexity of networked governance, because they leave no clear analytical route or tool through which to understand 'hybrid' governance which involves both the state and non-state actors exercising power, providing little insight into how network and hierarchical forms of governance interact (Bulkeley, 2005). A different approach to explain multilevel governance that is operating across 'vertical' and 'horizontal' boundaries is therefore required.

Decision-making is often conceived as a function of the exercise of overt power, described as the property of a single actor in which power is married to legitimacy (Hurd, 1999). Alternative understandings of decision-making through authority draw on theories of power as a social construction. These support an alternative account of the workings of transnational global environmental governance, stressing the shifting geographies of authority.

Authority is one of a number of types of power such as coercion, persuasion and self-interest, but is distinguishable from these by the presence of 'legitimacy' (Allen, 2003, Bernstein, 2011), supporting the accepted legitimate exercise of power without coercion or forceful persuasion. Authority comes from *'an interpretation of legitimacy as an inter-subjective and relational quality whereby actors within a given community come to regard institutions, rules and norms as those with which they ought to comply because they are right, proper or appropriate'* (Bulkeley, 2012, p.2429). Such authority may be accorded to both the state and to other actors, including, for example, scientists, markets, moral, ethical or faith authorities and NGOs. Rosenau (2002), for example, argues the authority of NGOs is based on a range of sources including: knowledge, reputation, issue-specific competence, expertise and membership. This interpretation then denies authority and power as the sole-prerogative of the nation state, and opens it up to a broad range of actors (identified by empirical study as being present (Bulkeley, 2005)), allowing for the required re-articulation of geographies of authority in governance.

This understanding of power through authority, as a function of social relations, changes the interpretation of location and reach. Instead of an achieved condition it is rather the outcome of complex and variable practice across multiple actors. An understanding of how governance is achieved then becomes not a process of establishing the authority of particular actors, seeking the 'source', but, rather, one of exploring practices and processes of authority (Stripple, 2007). This shift of focus suggests it is possible to understand the operationalisation of authority as a set of different modalities of cooperation - consent, consensus, and concord (Bulkeley, 2012) - two of which (consent and consensus) are a product of a conscious process in which actors use power in instrumental ways to achieve concessions or to generate commonality. The underpinning driver of such a shift in focus is seen as important to social relations (Foucault, 2009). The third modality, concord, is less a conscious process in which power is deployed instrumentally to seek concessions and rather a process of joint acquiescence.

Consent is grounded in a range of attributes, including expertise, suasion, and market potential (Rosenau, 2002). In its simplest form consent is the enlistment of voluntary agreement to the proposal of a second party. It has an instrumental quality in so much as consent will lead parties to act in ways that they otherwise might not have done (Allen, 2003). Evidence of consent within the realm of climate change governance, for example, can be seen in various arrangements concerned with monitoring of GHG emissions. The construction of consent requires parties engage in a process of generating and accepting authority. Consent is only established at the point where consent is enacted, a point where only when the actors recognise authority is 'worthy of acceptance' (Hajer, 2009). Bulkeley (2012) suggests successful attempts to create this worthy acceptance are characterised by three activities. First, they have, typically, included efforts to enlist a diverse array of actors with a view to claiming legitimacy and independency. Secondly, networks have served to meet needs amongst constituents who are obligated by their own rules and, thirdly, the process of creating, auditing, and authenticating standards have been critical to success.

Whilst consent requires some conscious act of bending the will of others, consensus does not require such use of power. It is rather the result of a variety of techniques through which actors coalesce around common positions or norms. One of the core approaches adopted is the description and uptake of best practice participatory or engagement tools through which not only can learning occur, but also by which common baselines for behaviour can be constructed.

Consensus is mutually constituted between and amongst actors who have regard for one another and who are willing to hold common agreement between themselves. Important to this form of authority is how the heterogeneity of interests are reformed into common agreement, which carries with it authority. The construction of consensus can be characterised by contestation that becomes resolved. Consensual governance can break down either in response to paradigm shift or as a result of failure of processes of ongoing mediation and renegotiation.

Concord '*emerges through doing those things that are naturalised discursively and normally*' (Lipschutz, 2005, p.766) operating through a process '*of bringing into agreement heterogeneous elements – social and material - in such a manner that they are taken for granted as authoritative*' (Bulkeley, 2012, p.2439). The practice of concord is strategic, characterised not only by the bringing into agreement of a diverse range of social actors and discourses, but also the instrumental use of framing tools such as press releases, targets, and, technologies.

Having been established, ongoing compliance within a concord mode relies on the construction of 'normal' expectations and actions of self-governing subjects. Key to the success of concord is the capacity of actors to make their presence felt, whether they be geographically close or distant. This ability to be 'present' is critical to how authority in this mode is spatially mediated. Bulkeley (2012, p.2440) illustrates this in the realm of climate governance where *'it is the mediation of socio-spatial relations within transnational climate governance arrangements through practices of 'making present' that serves to constitute concord as a mode of authority'*. If and how SAI interested or affected parties, and in particular local actors within small geographies, remain present in any ongoing process of consensus, consent and concord governance of a global commons is unknown.

In the context of SAI, this framing and the evolving relationships between actors and the technology, facilitated through dialogue, would be demonstrated in technology appraisal (Bellamy et al., 2013), i.e., through processes which inform tangible social choices, or commitments, about technologies and their governance, and provide for resolution of dissent. Early indications suggest scientists might be operating within this mode, using a consent, consensus, and concord model for their work and SAI implementation, having recognised the need for inclusive approaches to the development of governance in the light of evidence of negative public perceptions (Pidgeon et al., 2011, SRMGI, 2011). Researcher awareness of governance failings associated with other controversial technologies, including nanotechnology and synthetic biology, is also thought by Sarewitz (2010) to have informed their positioning in relation to SAI. There is also recognition by some SAI researchers that they are in danger of being perceived to be lacking humility as they work toward developing the means to control the climate, an ambition recognised by some that touches on hubris and which could undermine scientists' authority in the governance process (Keith et al., 2010, Morton, 2015).

Whilst these pluralistic approaches open up technology appraisal and appear more democratic, Stirling (2008) has argued incumbent interests are still able to close down options through the exercise of opaque power by the instrumental use of tools to direct policy, risk assessment, and technological uptake. Such power is exercised by socio-political actors (Collingridge, 1980) during processes of concord in particular. In the case of SRM these are visible in, for example, the 2009 Parliamentary inquiry, the Solar Radiation Management Governance Initiative (SRMGI), the Royal Society report, other academic assessments (e.g. (Bellamy et al., 2012)), as well as cultural activities including public debates and the media. Such appraisal approaches, if constructed from a commitment position, can become public education activities or top-down engagement (Owens and Cowell, 2002) whereby apparently bottom-up participation appearing as a process moving toward consensus might rather be a more top-down legitimisation of, for example, SAI over other geoengineering approaches (Wakeford, 2001)**.** The extent to which SAI appraisal to-date has been constructed in response to commitments to the technology is unclear although one key actor, David Keith in his book 'A Case for Climate Engineering' (2013), has taken the view that SAI may be the right thing to do. This may, in-itself, be constructing a deliberative appraisal process which is closing down consensus by steering towards predetermined outcomes.

Stirling (2008) argues this can be addressed in part through more open participative appraisal, but recognises this does not negate the power (identified by Collingridge (1980)), influencing the framing of appraisal processes such as through the choosing of policy questions, the construction of boundary remits of institutions, the terms of reference and memberships of committees etc.. Control of framing can then affect outcomes of the consent, consensus and concord process, especially when an appraisal process closes in on a technological choice (such as SAI) from the outset rather than establishing a solution to a challenge, in this case, anthropogenic climate change.

4.3 Governance summary

SAI is creating new global and global commons (GC) governance challenges that will require novel solutions. Consent, consensus and concord provide mechanisms through which dialogue about risk, uncertainty, ambiguity and ignorance might be incorporated into the construction of environmental governance. These processes of negotiation will create a rich tapestry of potential governance vectors, muddying the waters of what has previously been interpreted as a much clearer institutional, or regime model of governance, and will align more closely to real-world experience that allows divergent contexts, public values, disciplinary perspectives and actors interests to come to bear on governance processes, opening up access to plural interpretations of how SAI might be governed.

This interpretation allows for a more complete understanding of actors' roles and governance processes, recognising that what is not known is as important as what is known, and that no matter how much is believed to be known, there are no grounds for complacent confidence in the face of Rumsfeld's (2002) infamous 'unknown unknowns'.

Under such open approaches to governance, stylised upstream processes will be rejected in favour of open analytic and participative processes, across geographies and levels. Critically, as suggested by Wynne (2001) in relation to GMOs, these processes should be present in the early stages of SAI evolution, prior to the formation of tangible commitments, before institutional, economic and infrastructural attachments are made to particular technological pathways, making them concrete and leading to the allocation of resources, capital and research funding. Whether these approaches are in play is the subject of the empirical research discussed in Chapters 6 and 7.

4.4 Risk, uncertainty, ambiguity and ignorance

The risks associated with SAI create a key challenge for its governance. How risk might be interpreted, responded to, and incorporated through the governance process is uncertain. This section explores the nature of risk and presents the theory of SAI risk management that will be tested through the fieldwork.

Risk is the probabilistic chance that an event with negative impacts or harm/loss will occur (Knight, 1921). A risk is comprised of three critical elements: loss, the significance of any loss, and the uncertainty associated with loss (Yates, 1992). In the case of SAI, the further risk of not securing the benefits of SAI's capacity to mitigate climate change must also be considered.

A Blackett review (GO-Science, 2011), commissioned by the Cabinet Office and the Ministry of Defence to help inform their policy and decision making, identified three types of risk:

- those which most people would not necessarily identify and characterise (but about which many experts might have a reasonable understanding - for example a storm surge overtopping the Thames Barrier in London);
- risks which are identified, but about which little is understood (for example, severe space weather); and,
- risks which most, if not all, experts would struggle to identify.

SAI risk is best described as one where some, but not all, aspects of the risks have been identified. A risk, once identified, is normally characterised as either a high or low risk, leading to high or low loss respectively. Undertaking an action that has an associated risk, whether high or low, does not necessarily mean harm or loss will arise from the action (Poortinga and Pidgeon, 2003). The framing of risk as the chance of harm or loss can be problematic in the context of SAI. Physical loss that is quantifiable and measurable can be accounted for. It might, for example, be possible to quantify the cost of health related losses linked to SAI. However, SAI also has the capacity to cause harm or loss to the environment and human well-being which are unquantifiable and/or qualitative.

Further, quantifying loss is problematic. Whilst neoclassical environmental economists have attempted to put a price on the environment, they are unable to include a full account of the qualitative social and cultural values of it (see for example the UK National Ecosystems Services Assessment (UNEP-WCMC, 2011)). Although quantified benefits of action, such as introducing SAI, might then outweigh the quantifiable costs, this does not incorporate value in a broader sense. A cost benefit analysis, for example, that demonstrates that an intervention is economic does not mean it is either morally correct or politically acceptable. Using a physical loss risk model for SAI would then ignore distributional issues, including who should benefit and who should bear the cost. When valuing SAI, which has the capacity to cause harm in some regions and to bring benefit to others, this is further complicated, because it would be incorrect to assume the global population as a whole would benefit from a temperature reduction simply because the total benefits outweighed the total costs, given that not all communities would benefit equally, i.e., SAI would not be a common good in the strictest sense (Gardiner, 2013, Morrow, 2014).

Quantifying the value of loss also gives rise to intergenerational issues, in addition to those discussed in section 3.6. Judgements about the loss that might arise from SAI today, even when balanced against future potential losses caused by climate change, may not be compatible with the views of future generations who may, for example, have taken other effective climate change adaptation and mitigation measures, but might have to continue bearing the loss or cost of an earlier SAI intervention.

Uncertainty and ambiguity are key characteristics of risk and play an important role in the dynamics of risk management governance (Renn, 2008). Uncertainty is characterised by the lack of probabilistic odds being available to inform judgements about the expected likelihood of outcomes of any given actions (Adams, 1995). The lack of probabilistic odds does not however reflect ignorance of the existence and possibility of negative impacts or harm occurring as a result of any action. There is then, simply, no basis for predicting the odds of their occurrence. Uncertainty frustrates attempts to undertake a probabilistic assessment of risk, because of limited evidence, scientific disagreement, or an acknowledged ignorance amongst scientists about underlying processes (Aven and Renn, 2009, Filar and Haurie, 2010, Halpern, 2003). Kline and Renn (2012) have identified four forms of uncertainty:

- variability - different vulnerabilities across individuals, i.e., responses to identical stimuli vary amongst individuals;
- inferential error - systematic and/or random errors, including problems of extrapolating from small statistical samples, usually expressed through statistical confidence intervals;
- indeterminacy - stochastic relationships between cause and effect, non-causal or non-cyclical random events, or badly understood nonlinear, chaotic relationships; and,

- system boundaries – where restricted models limit the number of variables and parameters available.

Ambiguity adds further complexity. Whilst more evidence, data, and information might reduce uncertainty, they will not necessarily reduce ambiguity. Ambiguity has been identified as a situation of ambivalence in which different, even divergent, streams of thinking and conceptualisation exist in the consideration and interpretation about a single risk phenomenon (Feldman, 1989, Zahariadis, 2003). This ambiguity has been subdivided into interpretive and normative ambiguity by Stirling (2003). Interpretive ambiguity is driven by different assessments of evidence, where differing groups or individuals take the same evidence and interpret what the evidence means in terms of risk in different ways. Normative ambiguity reflects different concepts of what is regarded as a tolerable risk. Both then can give rise to divergent or contested perspectives on the severity or wider meanings given to a risk or threat.

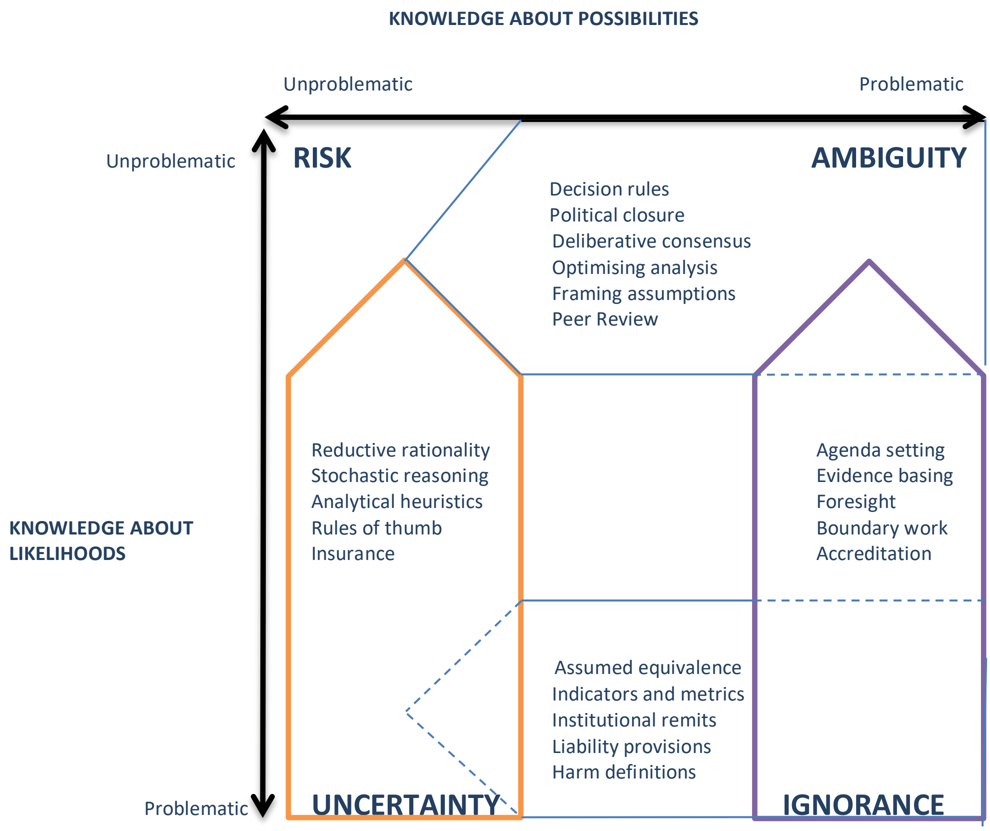
"Tolerable" in this context does not mean acceptable. Rather, toleration is only reached, if: those affected are told about and accept the nature and level of the risks; the risks are kept as low as reasonably practicable; and, the risks are reviewed periodically to see if they have changed or can be further reduced. This understanding that there is no sharp line between safe and not safe was first articulated in 1992 (HSE) in the Health and Safety Executive's Tolerability of Risk Framework (TORF). This adopts an intuitive, common-sense view that considers risks to be: unacceptable and so subject to the Precautionary Principle; or negligible by reference to everyday experience; or tolerable in exchange for the benefits of the activity that gives rise to the risks. The TORF sets out a scale of risk that shows the relationship between negligible, tolerable and unacceptable risks and, it identifies boundaries beyond which risk cannot be justified, where a risk can be tolerable and where risk does not worry people or cause them to alter their behaviour in any way.

Ambiguity might be particularly interesting when exploring the construction of risk perceptions about SAI. For some the risks of anthropogenic climate change might be viewed as tolerable when compared to the potential risks of SAI, yet for others that may not be the case. These judgements might be expected to be influenced not only by interpretive and normative ambiguity but also actors' perceptions of uncertainty about either or both the actuality of anthropogenic climate change, the effects of that climate change or the effects, both positive and negative, of SAI.

The condition of ignorance is where neither probabilities nor outcomes can be characterised. This state is different from uncertainty, which is able to focus at least on agreed types of harm, and different from ambiguity, where the parameters are unbounded or unknown, rather than simply contestable and under-characterised.

Stirling's (2009) heuristic model of responses to problematic knowledge, depicted in Figure 4.1 below, offers a gateway through which to convey appreciations of the role of these knowledge states. Its key message is that there are a wide range of tools available above and beyond a ubiquitous risk assessment hammer which, if

Figure 4.1 Methodological responses to problematic knowledge



(Adapted from (Stirling, 2009, p.36))

embedded in approaches to risk appraisal and its governance, could open up legitimate and plausible representations of knowledge allowing risk appraisal and its governance to be more inclusive of different types of knowledge.

In the top left of the figure conventional governance of science and technology, risk is grounded in high levels of confidence in the accuracy of both axes. Examples would include familiar deterministic systems such as structural or mechanical engineering. What is problematic is that success in this quadrant is taken to mean general sufficiency of the strict 'scientific' approach, and that even deterministic systems only operate deterministically under normal conditions which are exceptionally difficult to ensure even in closely controlled environments.

The strictly defined condition of uncertainty is located in the lower left quadrant. Here data and models are unable to allow risk assessors to assign a probability of harm arising. Such conditions are found in open, dynamic indeterminate systems such as extreme events arising from climate change. In this situation, the most scientifically rigorous approach would be to recognise that harm may or may not occur, and not to offer any quantification of likelihood. Any attempt to offer a risk-based understanding under this condition of uncertainty would not be scientifically rigorous; however, as Stirling (2009) notes, the term uncertainty is often presumed to accommodate the restricted risk-based methods of the upper left-hand quadrant.

In the top right, conditions of ambiguity exist where groups or individuals can take the same evidence but arrive at different interpretations of risk and tolerability. Ambiguity raises questions about how to compare benefits and different forms of harm in contexts of differing 'expertise', ontologies, ethics, and values. Therefore, attempts to reduce relevant knowledges to aggregated risk assessments are even less rational than when under conditions of uncertainty.

In conditions of ignorance, in the bottom right quadrant, it would be highly unscientific to predict potential futures in a risk context. Rather, practices and strategies that allow clear articulations of diverse knowledges with a view to enhancing awareness, reflexivity and humility should be pursued with a view to constructing more inclusive socially robust understandings, which should not be confused with a route to resolving ignorance in its own right.

In the context of uncertainty and ambiguity, risk then goes beyond being solely about the extent of any loss and the likelihood of its occurrence and becomes a more holistic conception. This allows a more comprehensive set of attributes to be brought to bear to recognising risk, opening up new ways of talking about risk and allowing for the introduction of more complex approaches to informing risk decision-making and its governance (GO-Science, 2011). Because it is not possible to enumerate either the final nature of any SAI deployment, nor what its impacts might be, this conception provides a useful model to inform theory of how SAI risk might be managed and the governance process conducted.

To examine these processes in the case of SAI and to describe the state of risk knowledge about SAI, a model developed by Ortwin Renn (2008) is used. This locates SAI risk in a management typology that suggests how risk might be reduced, with a view to opening up governance options beyond a precautionary 'no go' position. This model is explored below, and SAI fitted to it. However, because it forms an important option within the model the Precautionary Principle is explored first.

4.5 Clarification of the Precautionary Principle

The Renn model draws on the Precautionary Principle. This is an important concept that requires unpacking and examination in the context of SAI before it is used further. The rationale for the Precautionary Principle predates its inception. In its essence the Principle is captured in cautionary aphorisms such as *'an ounce of prevention is worth a pound of care'* or *'look before you leap'* and applies to institutions and institutional decision-making as well as individuals. The Precautionary Principle is generally understood to capture the intuition that it is better to be safe than sorry and therefore that actions should not be taken in advance of robust scientific evidence.

A primary foundation of the Precautionary Principle in environmental governance and an accepted definition of it is expressed in Principle 15 of the Rio Declaration of the Rio Earth Summit in 1992. This states *'In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'* (UNEP, 1992, p.3).

As noted in section 3.2, in 2010, the UN Convention on Biological Diversity specifically linked the Precautionary Principle to geoengineering calling on parties not to *'undertake climate related geo-engineering activities until there is an adequate scientific basis on which to justify them and appropriate consideration of associated risks to the environment and biodiversity and associated social economic and cultural impacts'* (CBD, 2010, p.5).

Whilst these definitional interventions help resolve some of the ambiguity about when it may, or may not be in precautionary interest to invoke the Principle, there remains some confusion surrounding it in relation to SAI (Hartzell-Nichols, 2012). The Principle may, at first glance, seem to permit SAI deployment and research as a precautionary measure against high impact climate change. However, in the context of uncertainty about the risks of SAI it may be inappropriate to deploy given the chance of significant harm to humans and the environment as a result; double jeopardy. This conflict is resolved through the application of a definition of the Precautionary Principle relevant to catastrophe offered by Hartzell-Nichols (2012), the Catastrophic Precautionary Principle. This is then operationalised through a decision-making framework to resolve the conflict and offer a different response to the threat of climate shocks.

4.6 Catastrophe Precautionary Principle

Neither the content nor nature of the Precautionary Principle has been clearly or consistently identified or applied, in either philosophical literature or in environmental policy (Elliot, 2010). Rather than thinking of the Precautionary Principle as a loose family of principles that share a common structure: (Hickey and Walker, 1995, Manson, 2002, Sandin, 2007, Tickner, 2003) or, as a decision-making procedure (Resnik, 2003) it should be recognised that the Principle cannot itself universally justify precautionary action. In the light of this complexity of meaning and interpretation, Hartzell-Nichols (2012) argues a Precautionary Principle of limited scope must be identified, defended, and consistently applied. This means that, rather than asking of a particular situation, 'what does the Precautionary Principle say in this case,' the question should be, 'is there a Precautionary Principle that applies in this case, and if so what does it require?'

This insight suggests that 'the' Precautionary Principle cannot be used to justify any and all precautionary action. If a Precautionary Principle is to have normative force it must have a unique *prima facie* moral obligation. This suggests a family of Precautionary Principles, with each Principle being independently identified and justified. This interpretation returns meaning and normative force to precaution in the limited cases in which it is morally called for. Therefore, if it is accepted that there is a moral obligation to protect against catastrophe then precautionary measures ought to be taken against those threats via the construction of a Catastrophe Precautionary Principle (CPP). This CPP is described by Hartzel-Nichols (2012) as where:

- threats of catastrophe are where millions of people could experience harmful outcomes;
- knowledge of the probability of harm is not required to warrant taking precautionary measures;
- precautionary measures must not create further threats of catastrophe and must aim to prevent the potential catastrophe in question;

- imminent threats of catastrophe require immediate precautionary action; and,
- threats of an imminent threshold or point of-no-return for effective precautionary action require immediate precautionary action.

This detailed articulation of the CPP provides the clarity missing in most formulations of the Principle, and constitutes appropriate precautionary measures against any particular threat of catastrophe. How that is operationalised on a case-by-case basis, for example, in relation to SAI must subsequently be determined. Assistance with this is offered by Hartzell-Nichol's (2012) decision-making framework having two aims:

- to determine whether the CCP generates a *prima facie* obligation to act; and,
- to determine an appropriate course of precautionary action for addressing a threat of harm that has been deemed to require precautionary measures.

These aims suggest that the first step is to understand whether a threat of harm constitutes a threat of catastrophe. Threats of climate change catastrophe would be those in which many millions of people could suffer severely harmful outcomes. Whilst the precise probability, characteristics, or timings of these harms is not known, the mechanisms by which they might arise (unabated GHG emissions trajectories and insufficient adaptation and mitigation) are increasingly understood through scientific research, making it reasonable to judge climate catastrophe as *a* possible future. For example, 80% of the IPCC 'reasons for concern' correspond to threats of catastrophe, per the definition in CPP (Hartzell-Nichols, 2012).

Therefore, the CPP does require precautionary measures be taken against these potentially catastrophic climate impacts. Following this decision the appropriateness of a precautionary action must be resolved. In the case of SAI this is complicated because, however small, it has the potential capacity to cause catastrophe. SAI must then be subject to the same examination, because precautionary measures taken against a particular threat of catastrophe are not exempt from CPP merely because they are precautionary measures.

CPP is a *prima facie* moral principle that is based on the claim that it is wrong to allow known threats of catastrophe to go unmitigated because of the magnitude of harm that may otherwise ensue. This does not mean that circumstances will never be such that significant risks cannot be taken, but if risky activities are engaged precautionary measures should be taken to mitigate the possibility of catastrophic outcomes. CPP will direct decision makers to choose among these precautionary options in favour of options with capacity for catastrophe, however small.

Whether SAI strategies will ever constitute an appropriate precautionary measure can only be answered through research. The latter is warranted given that the CCP decision-making framework's second aim, (to determine an appropriate course of action) provides scope for decision makers to consider all available *and future* precautionary measures, a set of considerations that could include research into novel approaches such as SAI. The technology can only become a viable precautionary measure against climate change if research can demonstrate specific methods will not create new threats of catastrophe.

4.7 Renn's model of risk management strategy

Attention is now turned to describing the state of risk knowledge about SAI and how it might be governed. Via the Renn model, SAI is located in a risk management typology that suggests how risk might be reduced with a view to opening up governance options beyond a precautionary 'no go' position. This model is explored below, and SAI fitted to it.

Renn's (2008) model of risk management strategy, based on the 1999 annual report of the German Advisory Council on Global Change (2000), recognises and accounts for uncertainty and ambiguity through holistic concepts of risk that go beyond probability and loss to include a set of nine attributes to help inform risk characterisation. These are: extent of damage; probability of occurrence; incertitude; ubiquity; persistency; reversibility; delay effect; violation of equity; and, potential of mobilisation. Critically, it recognises the importance of perceptions of risk and their effects on actors' risk assessments.

Risk perceptions of new technologies vary across actors and publics and can have significant effects on their governance and uptake (Bubela et al., 2012). For example, polarisations of views between publics and other interested or affected parties where issues of trust, confidence, ethics, perceptions of procedural fairness and, in some cases, ideologically based framings of a technology as inherently hazardous, have affected the evolution of governance and deployment of GMOs, nanotechnology and synthetic biology (Siegrist et al., 2012, Wynne, 2001, Tait, 2012, Poortinga and Pidgeon, 2005, Pidgeon et al., 2012). The explicit recognition of the need to incorporate such diverse positions into what would become a collaboratively derived risk assessment measure makes the model particularly useful for application to SAI.

The model distils the nine attributes into six risk classes:

- **Damocles**. A very high potential for damage but a very low probability of occurrence, e.g. technological risks such as nuclear energy and large-scale chemical facilities.
- **Cyclops**. The probability of occurrence is largely uncertain, but the maximum damage can be estimated, e.g. natural events, such as floods and earthquakes.
- **Pythia**. Uncertain risks, where the probability of occurrence, the extent of damage, the allocation and the way in which the damage manifests itself is unknown due to high complexity.
- **Pandora**. Uncertainty in probability of occurrence, the extent of damage and its manifestation where the probability is derived from credible assumptions rather than evidence form scientific appraisal.
- **Cassandra**. Probability of occurrence and extent of damage are known, but there is no imminent societal concern because damage will only occur in the future. There is a high degree of delay between the initial event and the

impact of the damage.

- **Medusa**. Low probability and low damage events, which nonetheless cause considerable concern for people. Often a large number of people are affected by these risks, but harmful results cannot be proven scientifically.

In turn the six classes are situated within one of three risk categories, for which Renn proposes different risk management strategies: 'Science Based', 'The Precautionary Principle' and 'Discursive' (see Table 4.1). Whilst these six classes are comprehensive in their classification of the potential for damage and probability of occurrence, and intrinsically recognise the role of publics' perceptions in the construction of risk, the model does not explicitly account for secondary risks that might arise out of an action or inaction.

Table 4.1 Risk classes, risk categories and risk management strategies

RISK CATEGORY	RISK CLASSES	RISK MANAGEMENT STRATEGY
Science Based	**Damocles** **Cyclops**	Seek to reduce disaster potential through increased knowledge. Ascertain greater certainty about probability. Take measures to increasing resilience. Seek to prevent surprises.
Precautionary	**Pythia** **Pandora**	Take a strategic decision not to act and to implement the Precautionary Principle. Seek to develop substitutes to achieve similar outcomes with less risk. Improve knowledge. Where appropriate, take measures for containment and reduction. Develop emergency management plans and tools.
Discursive	**Cassandra** **Medusa**	Consciousness and confidence building and public participation. Risk communications. Contingency management.

Adapted from (GO-Science, 2011, Renn, 2008)

4.8 Fitting SAI to the model

SAI is now fitted to the model, an appropriate risk class identified and the resulting expected risk management strategy is described.

The decision about which class to locate SAI in is important as the model suggests different risk management strategies for each. The risks that might arise from SAI use are currently highly uncertain and ambiguous; however, if it is accepted, as suggested by Baum et al. (2013), that maximum loss could be globally catastrophic, then SAI aligns with Renn's Cyclops risk class. If the potential for globally catastrophic loss is rejected and, the potential for loss considered 'unknown', then either the Pythia or Pandora class would be more appropriate.

So, a judgement has to be made about the likelihood of catastrophe. Catastrophe in definitional terms is an event that causes great and unusually sudden damage and suffering. This temporal rapidity would not be a characteristic of SAI if, as proposed by most proponents, it were introduced over an extended timeframe with aerosol deposition and climate cooling ramping up slowly (Keith, 2013). If SAI were to be introduced with a view to delivering limited temperature reduction using relatively small quantities of aerosol, the likelihood for catastrophic loss would be negligible (Keith, 2013). Assuming any SAI interventions will aim to reduce global climate warming by up to and by no more than 50%, the likelihood of catastrophe is diminished.

Risks of SAI under this assumption are mapped against Renn's risk classes in Table 4.2. This suggests, in the light of the discussion of catastrophe above, and the distribution of risks in the table, that it is appropriate to locate SAI in the Pythia or Pandora classes and hence the precautionary risk category. The Pythia and Pandora classes both include highly uncertain risks where the probability of occurrence, extent of damage and the way in which the damage is manifested, are unknown. The unknown probability of occurrence relevant to both classes is helpful in the context of perceptions of risk, in that actor and public perceptions of SAI risk are broadly unknown and may or may not directly affect the rate of deployment, meaning that probability is unknown. Secondly, the inclusion of uncertainty about how damage is manifested allows for consideration of both the effects of

Table 4.2 Mapping SAI risks against Renn's risk classes

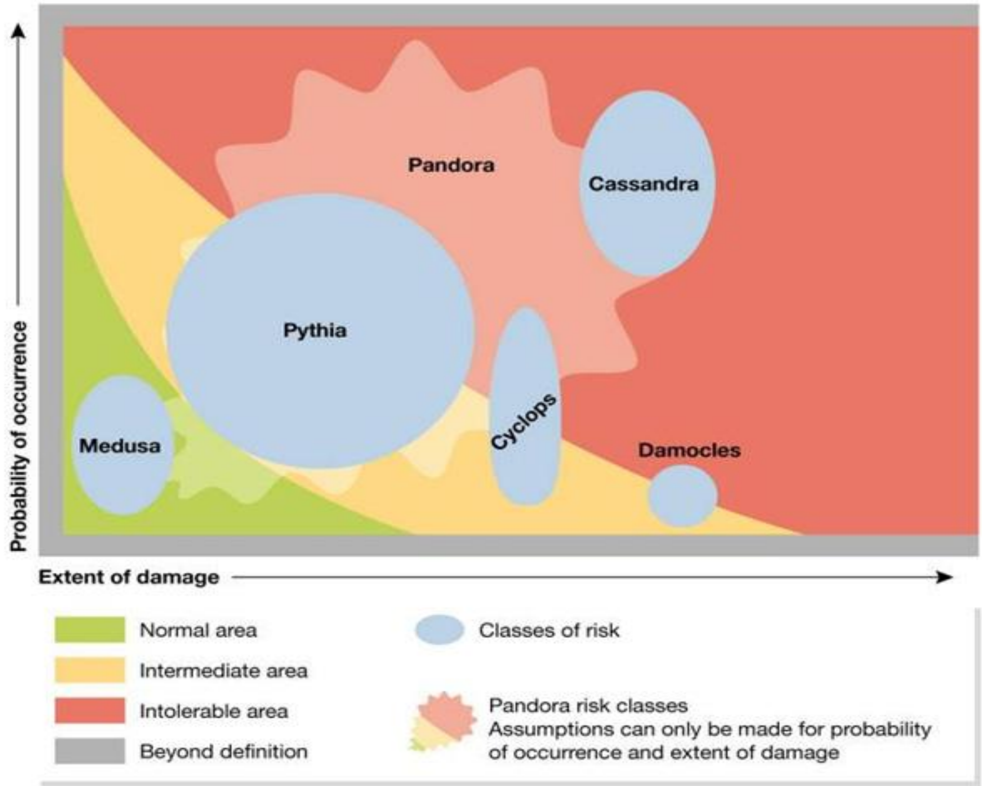
RISK CLASS	CLASS DESCRIPTION	POTENTIAL SAI RELATED RISKS
Damocles	A very high potential for damage but a very low probability of occurrence.	Significant, unpredicted temperature reduction. Potential for destructive military use.
Cyclops	The probability of occurrence is largely uncertain, but the maximum damage can be estimated.	Diminished climate change mitigation – unabated GHG emissions effects on ecosystems, oceans and global energy supply.
Pythia	Uncertain risks, where the probability of occurrence, the extent of damage, the allocation and the way in which the damage manifests itself is unknown due to high complexity.	Financial loss and cost, e.g. changes in food production, drought and flooding. Effects on regional climate. Political instability affecting balance of power in any thermostat setting decision-making process. Increased rate of extreme events. Bounce back damage following abrupt termination. Human error – design, manufacture and operating failures. Ozone depletion - increased ultra-violet flux to Earth's surface. Unexpected impacts and implications 'unknown unknowns'. Large-scale human migration/SAI refugees.
Pandora	Uncertainty in probability of occurrence, the extent of damage and its manifestation where the probability is derived from credible assumptions.	Continued ocean acidification (without climate change adaptation). Sulphate or other particle fallout related deaths. Changes in plant photosynthesis capacity – unknown rate of change and effects. Enhanced acid rain potentially exceeding biological thresholds. Aerosol fallout cirrus cloud seeding effects on balance of radiative forcing. Financial opportunity costs. Whose interests rule? If SAI is delivered by private companies will the environment and humanity or shareholders and the profit motive drive decisions?
Cassandra	Probability of occurrence and extent of damage are known, but there is no imminent societal concern because damage will occur in the future. There is a long delay between the initial event and damage.	Reduced sunlight reduces solar power output.
Medusa	Low probability, low damage events, which cause concern. Often a large number of people are affected by these risks, but harmful results cannot be proven scientifically.	Global whitening - 'no more blue skies'.

anthropogenic climate change and uncertainties about the extent to which SAI would or would not mitigate those, as well as uncertainties about the risk of SAI *per se*. Critically, the key difference between the Pandora and Pythia class is that in the latter the allocation and the way damage is manifested is unknown due to high complexity, whilst within the former damage manifestation is derived from credible assumptions. Without any clarity about what levels of SAI may or may not be deployed with a view to what affect and in the context of no fieldwork and only very limited laboratory experimentation and modelling, credible assumptions about the effects of SAI cannot be made at this time. SAI should therefore be situated in the Pythia class.

It is now possible to examine the proposed risk strategies that arise from this classification. The purpose of the risk management strategies is to minimise risk and allow progress through deliberate measures and actions. Renn's model offers a pathway toward this, locating the defined classes of risk into one of three risk bands, normal, intermediate and intolerable (see Figure 4.2) and proposes strategies for moving toward normal or acceptable risk from which implementation can be normalised. SAI, as a Pythia class risk with capacity to create highly persistent damage is situated in the 'unacceptable range'. The model suggests five strategies for such a risk:

- taking a strategic decision not to act and to implement the Precautionary Principle;
- seeking to develop substitutes to achieve similar outcomes with less risk;
- improving knowledge; where appropriate, taking measures for containment and reduction; and,
- developing emergency management plans and tools.

Figure 4.2 The Renn model's pathways through action



Source: Go-Science (GO-Science, 2011, p.42).

If these strategies cannot be delivered, SAI would move into the prohibited area and not be pursued. If, however, knowledge expansion positively resolved complexity about damage manifestation, SAI would then move to Pandora as the probability of occurrence and the severity of effects could be drawn from credible assumptions, opening up a theoretical route to future deployment.

The next step in the risk management strategy would be to determine the damage potential more clearly. If there were reasons to believe that substantial damage through the use of SAI were possible, without probabilities of that being known, then the risk would be relocated to the Cyclops class from which, as can be seen in Figure 4.2, the risk can move to a variety of other classes. If, for example, it is possible, through additional evidence, to determine the probability of occurrence and this is relatively low, then SAI could be categorised as a member of the Damocles class, a risk characterised by high severity and low probability. If, though, probability were found to be high without time lag, SAI would again be located within the prohibited area. If this were not the case SAI would migrate towards the

Cassandra category. Having located in the Cassandra category, if measures reduced the harm potential of SAI, it could then locate within the normal area where deployment, having taken account of risk, uncertainty and ambiguity, is tolerable. On the other hand if the risk of disaster remained high despite efforts to minimise it, SAI would locate in the Damocles class from where can move into the normal area through knowledge improvement and taking measures to reduce the potential for disaster.

If attempts to reduce risk fail, a fundamental decision about whether the benefit associated with SAI would be so substantial that the risk should be tolerated, would have to be taken. A position analogous to adopting last resort SAI measures when the risk is high, but not expected to be as high as the catastrophic climate change it is designed to mitigate.

For all risks classes, Renn recommends that the best route into the normal area is via the Medusa class which requires a clear focus on discursive public risk debate. Even if, as noted above, the probability of and potential for damage is very low, steps aimed at engaging publics, building confidence in the technology, institutions involved in its development, deployment and monitoring and risk management are essential. As such they should be an integral part of the development process, not only whilst situated in Medusa, but as a risk technology cascades through classes.

The empirical research will test the extent to which SAI might fit this model exploring how various actors assess the risks and how they think they might be incorporated into future governance. It will explore how actors characterise risk, whether they believe intolerable risks can become tolerable and whether they will actively seek to resolve uncertainties.

4.9 Summary of theoretical framework

A range of models of environmental governance have been discussed and most appear insufficiently to inform understanding of global environmental governance in the context of a technology that has the capacity to change intentionally the planetary system or multiple Commons. Bulkley's (2010, 2012) theory of governance by consent, consensus and concord suggests itself as a useful framework through which it may be possible to understand SAI governance. In addition, given SAI may be a high risk technology, Renn's (2008) theory of risk management is proposed as a typology to understand SAI risk and suggest how risk management will evolve.

The empirical research conducted for this study uses qualitative research to test the appropriateness of these two theories. The research method is discussed in Chapter 5. It explores how various interested and affected parties believe SAI risks will be managed and the characteristics of the governance environment that may evolve.

CHAPTER 5 - RESEARCH METHOD

5.0 Chapter overview

This chapter establishes the method selection criteria and examines two potential qualitative approaches. The case for semi-structured senior stakeholder interviews is established and a pilot study presented. Fine-tuning of the method, in the light of lessons learnt during the pilot study, is discussed. The senior stakeholder sample frame and the characteristics of each actor group in the sample are given. Prior to presenting the findings in Chapter 6, 7 and 8, how the interview evidence is used to test the theoretical framework is also discussed.

5.1 Introduction

Given the theoretical insights established, it was critical that the method be able systematically and reflexively to elicit perspectives on what governance of SAI might look like, and how it could operate. A positivist approach, which is that knowledge can be gained from positive verification of the observable rather than from, for example, introspection or intuition, is adopted in this study. This gives rise to a number of underpinning principles:

- it is possible to discern discrete perspectives on governance, and identify differences in these between and within groups of interested or affected parties;
- patterns and regularities can be elucidated and analysed;
- empirical analysis can illuminate understandings of how actors' perspectives are constituted and the kinds of patterns, if any, that emerge between them; and,
- conclusions made may have normative implications for understandings of how governance might evolve under conditions of risk, uncertainty, ambiguity and ignorance.

5.2 Method selection criteria

If insights into how knowledges, understandings, and evaluations about SAI governance are to be constructed and rendered salient, the method had to give access to the discourses which contribute to, and shape the ways in which the social actors understand, represent, and interpret alternatives. In order to open up this research, to allow for a plurality of views and inherent uncertainties to be incorporated, a method that addressed these issues by assessing the expected divergent socio-technical framings of SAI was required, suggesting that a qualitative method was most appropriate.

Since this research is comparing the views of actors across a range of backgrounds and interests in a contentious technology area, a method was required that enables accurate and nuanced elicitation of perspectives on governance, such that associated (and/or) systematic patterns may be identified and robustly analysed. Based on this, the method criteria were that it:

- should allow for normative judgements concerning evaluations of particular governance scenarios, meaning that participants can validate outcomes themselves;
- would be able to incorporate multiple views in a symmetrical fashion that does not unduly privilege one type of perspective;
- could elicit rich contextual insights; and,
- be resource efficient, convenient and accessible to participants.

In the light of these criteria, two methods suggested themselves, interviews and Q method. These are now discussed.

5.3 Q Method

Q method was developed in 1935 by William Stephenson (1935). The aim of the method is to gather and explore the variety of accounts individuals construct in response to stimuli, rather than seeking to obtain ‘truths’, and is underpinned by a notion of finite diversity (Stainton-Rogers, 1995). Q method emphasises patterns of interrelations between elements or stimuli, and these patterns are irreducible to their constituent parts. It is not concerned with the diachronic or temporal unfolding of patterns or views; rather it shows how subjective input can produce objective discursive structures that are relatively stable over time. Importantly, the Q method process is often supplemented with further empirical data, normally comprising follow-up interviews to tease out individuals' constructions and their rationale.

Prior to commencing fieldwork, a Q methodologist will construct a set of signifiers, known as a Q set. These are stimuli to trigger a subject's search for meaning. They can take any form, written, spoken or non-linguistic. The construction of the Q Set is critical to the success of the study (Brown, 1997).

The Q Method participants are required to 'Q sort' or order each item in the Q Set along a given axis such as agree strongly / disagree strongly etc.. The 'Q Sort's then comprise the raw materials for data analysis upon which a factor extraction is conducted to generate portraits of shared configurational patterns of views from which descriptive or normative aspects of each can be extracted.

Q-methodology has a number of weaknesses, not least that it can be very time consuming and resource intensive (Karim, 2001). Importantly, the researcher is required to take decisions about rankings of sorts, which will have an effect on the findings, and it can be very difficult for the researchers to explain why they took the decisions they did (Watts and Stenner, 2005). In addition, participants often find a Q-sort difficult to complete, particularly if their perspectives do not align well with the researcher's Q set (Akhtar-Danesh et al., 2008), a risk that is of concern in the case of SAI given the incertitude that surrounds the technology.

5.4 Semi-structured interviews

Semi-structured interviews offer an alternative to Q-Method. An interview is a managed verbal exchange that implies a value on personal language as data. They are highly reliant on the research and communication skills of the interviewer (Ritchie and Lewis, 2003, Gillman, 2000) who must be able to give the interviewee the time in an appropriate environment to express their thoughts, views and ideas (Clough, 2002). It is critical that appropriate clearly structured questions are constructed to guide the process through the areas of interest. However, opportunity must also be available for active listening, pausing, probing and ensuring the interviewee is given maximum opportunity to talk freely. Strong interpersonal skills requires the capacity to establish good rapport, including with humour and humility, if trust and confidence of the subjects is to be secured (Opie, 2004).

Semi-structured interviews are conducted with a fairly open framework allowing focused, conversational, two-way communication. The use of an interview guide that leaves open the opportunity for the respondent to bring their own ideas and thoughts to bear during the process means that the research study is not solely reliant upon the researcher accurately predicting all areas of interviewee's interest and allows for the unexpected to be included. Semi-structured interviews open up rather than close down spaces giving full flexibility for meanders, if appropriate, to form around central themes, whilst keeping the process on track and ensuring the key topics and questions are addressed. A good semi-structured interview falls somewhere between a controlled environment and participant observation but critically allows for comparison between more than one interview.

However, it is important to recognise and address weaknesses of the method. The 'interviewer effect', that is how participants perceive the interviewer, and in particular perceptions of gender, age and ethnic origin of the interviewer, has a bearing on the amount of information people are willing to divulge and their honesty about what they reveal (Denscombe, 2007). In addition demand characteristics, described by Gomm (2004) as when an interviewee's responses are influenced by what they think the situation requires, can affect the value of interview material. Gomm suggests that these issues can be addressed by being clear at the beginning of an interview about what the purpose and topics are and seeking to put the interviewee at ease.

A further issue is that comparability between interviews can be diminished or even lost if the sequencing and wording of questions is widely differentiated between interviews. However, what is potentially lost here may be gained by allowing interviews to develop their own coherence, which itself can be analysed. If interviewees do become particularly diverse this can be overcome, in part, by the use of detailed content analysis.

5.5 Method choice

Having outlined the two methods, they are now tested against the selection criteria set out in section 5.2.

Should allow for normative judgements concerning evaluations of governance scenarios, meaning that participants can validate outcomes themselves

Whilst Q method can deliver normative judgements, those judgements cannot be validated by participants nor can rationales for the positions given in the Q Sort be captured, unless the Q sort is followed by a further semi-qualitative method, for which there were insufficient financial resources available in this study. The method does not meet this criterion. On the other hand, within the interview environment subjects are invited to rationalise and explain their judgements and these can be verified through probing questions to ensure the interviewee is satisfied with an answer and indeed that the interviewers understands the response fully.

Be able to incorporate multiple views in a symmetrical fashion that does not unduly privilege one type of perspective

Q method allows participants to express subjectivity, in whatever situation is of interest to the researcher, and seeks to expose patterns of relationships in those expressions. The interview also allows for the incorporation of multiple perspectives and points of view unless yes/no closed type questions are used. Both methods therefore meet the needs of this criterion.

Elicit rich contextual insights

Accessing these types of insights is fundamental to this research, if it is to provide an understanding of why different interpretations of governance approaches exist. Q method is unable to draw out the depth of background information that interviews offer. Once the Q Sort is completed a statistical analysis is conducted and conclusions about how participants' views relate to the overarching factors are drawn. Unless there is a further iteration with the participant about the findings, generally in the form of an interview, Q method is unable to capture background insights - a critical shortcoming in light of the requirements of my research.

Q Method fails to meet this criterion.

Be resource efficient, convenient and accessible to participants

Neither method requires access by the subject to bespoke software or other equipment, and although Q method is relatively easy to explain and requires minimal preparation by the participants, it is less well understood than traditional interviews of which many likely interviewees will have had previous experience. It is also suggested that using an established, well known, method may secure more positive responses to subject requests, than if a less well known method such as Q were used (Robbins and Krueger, 2000).

5.6 Method selection summary

On balance, given that interviewing meets more of the substantive research criteria, and because a single Q Method often requires a follow up interview, interviews were considered likely to be more efficient, less resource intensive and less inconvenient to the participants. In addition, interviews have considerable capacity to incorporate unexpected or unimagined perspectives. Such perspectives are far less easily incorporated into a Q Set, which is a construct broadly representative of the opinion domain and the types of issues or items that the subjects are likely to consider. This is particularly salient in the case of SAI governance about which there is very limited empirical evidence to-date. Therefore, in the particular circumstances of this study, I believe a semi-structured interview was the most useful tool to deliver the study objectives.

5.7 The pilot study - introduction

Given the novelty of SAI, a pilot phase was conducted to explore whether the areas of interest could be addressed by interviewees. In effect, the role of the pilot study was to understand what questions could be meaningfully asked, usefully answered and whether the research questions as set out could be addressed. A single pre-pilot interview was conducted to test the questionnaire and the practicalities of telephone interviewing prior to commencing the formal pilot phase. The interviewee was an established academic with a track record of publishing about geoengineering in peer-reviewed journals and wider policy engagement about the topic.

5.8 Pilot study ethics

Before making contact with any research subjects University of Southampton ethics approval was applied for and given for the pilot phase (University ethics approval reference 13766 see Annex 2).

5.9 Pilot sample

The participants were drawn from three communities that the Renn risk management strategy theory suggests will be active in the governance process (2008):

- active researchers from both the physical and social sciences;
- actors in the policy and governance world; and,
- the commercial sector.

Six interviews were completed. Two of these were conducted on a face-to-face basis, four by telephone. Of the six, three were physical scientists who have worked in the broad geoengineering field and one a social scientist working in the SRM field. Four of these academics had published work on SRM and/or geoengineering in peer-reviewed journals in the past five years. One interviewee represented the government sector, with over 30 years' experience in environmental governance, and the final interviewee, came from the commercial sector and had also engaged widely with the academic environmental governance research community.

During the setup phase some of those invited to interview were highly cautious about agreeing to participate. Whilst none of those who expressed caution declined the request, it was necessary to have some pre-interview discussions with three. The key concerns related to: how would confidentiality be guaranteed, particularly in the case of the interviewee from the private sector; and, to what use or purpose the research was being conducted, including some concerns that there might be a remaining relationship between myself and my previous employer, the Economic and Social Research Council or Research Councils UK (RCUK). During the interviews some light was shed on why some of the participants were concerned about any remaining relationship, these participants felt that some of the funders' and government's geoengineering strategies were being covertly planned to fulfil some hidden strategies.

The evidence arising from the analysis of the pilot interviews must be considered anecdotal. The purpose, then, of the pilot was to test the research approach, to explore whether it was possible to undertake empirical research through interviews to inform debate about the governance of SAI. In effect to test whether it was possible to ask meaningful questions about this agenda at this stage in the development of the technology.

All seven (including the pre-pilot) interviews were transcribed in full by the interviewer although verbatim facsimile transcriptions were not prepared in the light of literature that questions the possibility of constructing a verbatim transcript (Lapadat and Lindsay, 1999, Mishler, 1991). That is, all words spoken during the interview were transcribed. However, where the interviewees paused for a particularly long time, repeated words consecutively and used normal vernacular utterances, aside from where it led weight or context to the interviewee's comments, these were not transcribed.

Having completed transcriptions of the interviews, these were transferred into the qualitative data analysis package NVivo 10. The purpose of using NVivo was to provide a set of tools to assist in undertaking the analysis rather than actually to conduct it. The software was not used to supplant time spent reading and becoming immersed in the data, which remained a critical part of the process. It did, however, help increase my effectiveness and efficiency during the learning of the material. NVivo's main function during the process was to provide a facility to help manage the data, opening up flexible routes to examining meanings whilst helping initial coding to be more methodical, thorough and attentive.

During this initial phase it would have been inappropriate to seek conclusions to the research questions. However, it did provide an excellent opportunity to think through how the second stage analysis might be conducted. In particular, it provided an opportunity to construct and test coding frames and metadata in the light of concrete material. This did prove useful and was transferable to the main study and helped organise and manage initial ideas to facilitate rapid access to conceptual and theoretical insights downstream.

During the initial analysis the data was examined in two ways, inductive and deductive. Whilst these produced different coding, outputs and perspectives on the material, it was helpful to test the two approaches revealing which was the more appropriate for this study, as discussed below.

5.10 The inductive approach

The objective of inductive analysis is to move from specific observations to broader generalisations and theories. This is often described as 'bottom up' or 'grounded theory'. The data are reviewed for repeated topics, ideas, concepts or elements that are then coded and extracted from the raw material. As the numbers of codes or categories expand they are then grouped into concepts that may become the basis for a new theory. It is through coding that the conceptual abstraction of data and its reintegration as theory takes place. Substantive coding was used. This includes both open and selective coding practices: fracturing and analysing the data, initially through open coding for the emergence of core categories and related concepts. Saturation was achieved when no new properties or dimensions emerged from continued coding and comparison.

The approach was very open ended and identifying saturation was challenging. This may reflect inexperience, although it is reported as a common issue in grounded theory (Holton 2007). A large number of topics and somewhat fewer concepts were quickly identified and coded. This was subsequently rather less helpful in terms of constructing meaningful and insightful perspectives than expected. Fifty nine inductive categories were constructed with data coded against each.

5.11 The deductive approach

A deductive approach to coding is narrow in nature and focuses on the testing or confirming of ideas or hypotheses cycling from theory to observations and back to theory in a 'top-down' approach.

Prior to commencing the deductive coding, hypotheses were constructed and tested through the collection of evidence that informed the deliberation of the hypotheses. Hypotheses were constructed and examined to explore the methodological experience, and to help inform decisions about the approach to the main study.

5.12 Initial findings from the pilot phase

Despite the small number of interviews the analysis from the pilot did suggest how the main study might be directed. A brief discussion of the findings follows.

The pilot interviews (see Annex 3 for copy of schedule) suggested that interested or affected parties have not yet paid attention to the governance of the global commons. This suggests the key focus on the commons in the research question was perhaps inappropriate and that it is not a critical location for current SAI governance debate.

Half of the interviewees mentioned a set of actors, described by one as 'progressive communities' that engage in a hybridity of environmental, social and economic issues such as climate change, sustainability, civil rights, the protection and enhancement of human rights, global social justice and technological futures, pursuing joined-up action around global scale holistic visions of alternative futures. There was some suggestion that these progressive communities might be more likely to engage in debates around geoengineering and its governance than more traditionally understood environmentalist actors. In the light of this, a more detailed consideration of the characteristics of the actor groups identified by the theoretical framework and confirmed by the pilot interview findings is offered.

A suggestion came to light during the pilot that governments and the science policy community are distancing themselves from SAI and geoengineering, seeking to close down options for its appraisal. This contention is explored in the main study as a new area because, if there is evidence to support this view, it would support Stirling's (2008) proposition that incumbent interests will take measures to close down and control the appraisal of risky technology. It also raises questions about how those actors are interpreting the 'emergency measure' framing, in which support is only given to SAI as a response tool. If there is a withdrawal or decline in engagement with SAI does this reflect a belief that emergencies are so unlikely as not to warrant investment in the broadest sense, or are there other underlying factors at play?

SAI literature raises important questions about the governance of intergenerational effects and risks (Bellamy et al., 2013). Issues flagged during the pilot interviews also included intergenerational responsibility and rights. The interview schedule used in the pilot phase did not encourage respondents to reflect on such issues, therefore the design was changed to allow them to be explored in the main study.

It was noted during the hypothesis testing that to test the Renn model properly it is necessary to explore whether deployment could ever be acceptable. Some evidence to inform this consideration came through the pilot interviews. However, some explicit attention to whether risks associated with SAI were, or could ever be tolerable, to complement an existing question about whether there could be circumstances under which contestation might be resolved, were included in the main study.

5.13 Review and discussion of pilot phase

A number of lessons were learnt during the pilot phase, which were drawn on to improve the main study. Four pilot interviews were undertaken on the telephone with the remainder conducted face-to-face. The telephone interviews did not appear to constrain the interview experience or discourage interviewees from opening up and speaking frankly. However, the telephone interviewing did lead to some technical issues that were resolved prior to the main study.

The interviews were recorded in full, having secured the interviewee's permission to do so. Recording quality was variable. This led to difficulties during transcription. The face-to-face interview recording quality was significantly better than those conducted on the telephone. In the light of this experience a high quality microphone was used for the main study.

During the pilot interviews all of the participants were open and talked freely, answering the questions without significant difficulty. Only one subject required any prompting and then this was only where a question had taken them outside of their normal area of expertise. Although the main phase brings individuals with considerably less expertise of SAI into the study, on balance the pilot study suggested that the semi-structured interview format will produce rich material allowing participants to express a very broad range of ideas.

The pilot phase sample only included white men; however, the main study sample is more inclusive (see section 6.2). Some interviewees' hesitancy about participating because of concerns about their confidentiality, anonymity and my independence from any research funders or science policy institutes was an important issue, and I was acutely aware of this when I was interviewing previously known individuals, some of whom I had worked with, some in the context of geoengineering. This may have affected the nature and content of their contributions and potentially my interpretations of their meanings, understandings and purposes during the interview process.

Whilst having a semi-structured interview schedule is helpful in ensuring commonality of questioning, I cannot be certain that I did not pick up on or use signals and interpretations that I might not otherwise have, given my previous relationships with some of the participants. Whilst this was likely to occur less frequently during the main study, it was important to be cognisant of this during that phase. On two occasions where I felt, on reflection, that this may have been an issue during the main phase I took my interpretations back to participants for validation. Secondly, wherever I draw directly from such individuals' contributions in the main phase analysis I seek to embed the perspectives drawn from those interviews within the broader contexts of the wider sample.

The interviewees, in both the pilot and main study, had all, to some extent, previously been engaged in the geoengineering debate as described in section 5.26. To address concerns about potential links to research funders and the wider science policy community the approaches to potential interviewees in the main phase were very clear that there would be no link or association between the study and any research funders or other agencies. The Participant Information Sheet, for example, makes clear statements that the study is entirely independent and that I have no remaining links or on-going relationship with RCUK, any of the research councils or other science policy bodies, despite having an ESRC award for this work.

The deductive approach to the analysis proved useful and was followed in the main phase. The approach suggested the method would provide a positive or negative verification of the theoretical framework during the main study. Such insights were less readily available via the more introspective or intuitive approach of grounded theory that were tested during the pilot phase.

5.14 The main study - introduction

The research questions, prior to the pilot interviews were focused on the global commons, they were:

- how can governance of the global commons be conducted in conditions of uncertainty;
- how can stakeholders respond to the global commons governance challenges posed by SAI; and,
- how can SAI and global commons governance develop in current conditions of technical, social and political uncertainty?

As noted earlier, following phase one the overarching concentration on the global commons no longer appears appropriate. Therefore, the research questions have been revised to focus on issues that appear from the evidence of the pilot phase to be more fully explored. They are:

- how might deployment risks be incorporated into SAI governance; and,
- might SAI governance be plural?

5.15 Sample frame and sample

The theoretical framework suggests a shift away from the traditional understanding that nation states are solely responsible for, or capable of, governing the global environments and suggested that a wide range of interested or affected parties would be engaged in the governance of SAI including:

- the global political community focused around global institutions;
- academics and scientific institutions;
- NGOs, state actors in government;
- the commercial sector; and,

- security and defence interests.

The Phase I interviews supported this suggestion and these expectations are reflected in the sample frame summarised in Table 5.1 and the groups included are characterised below.

Table 5.1 Sample frame

GROUP	EXAMPLES	RATIONALE FOR SELECTION
Academics: Natural Scientists Social Scientists	Individual research scientists actively engaged in the development and study of global environmental change and SAI or GE.	Scientists have been at the heart of the governance debate about SAI. They have technical experience and insight to the challenges that science and technologies can pose to governance and policy-making.
Corporate interests, including military corporations	Corporate representatives with a potential commercial interest, including insurance, financial and military in the GC or SAI.	A market or related professional interest in either SAI business opportunities, or threats.
Global institutions	Institutions with a mandated responsibility for environmental governance.	These institutions are central to global environmental governance and regulation and, with nation states, are responsible for governance decisions that affect them.
Non-governmental organisations and other independent actors.	Pressure and interest groups active in areas relevant to the GC and SAI.	A number of NGOs have been active in debates about SAI, pro, anti and deliberative. Other hybrid environmental, social and economic independent bodies.
Scientific Institutions	National and international research funders and science representative bodies.	Interests will range from ethical agenda to funding policy.
Government bodies	Government bodies or departments that have remits overlapping the broad research agenda. The sample will draw from UK and other states.	Policy interests in the deployment and effects of SAI and changes in the GC. Responsible to the public for the governance decisions that are made and related ramifications.

5.16 Actor characterisation

Each of the actor groups have distinct characteristics and are expected to bring different perspectives to the study. These groups are now characterised in terms of their essential nature and the interests they may have in SAI and its governance.

5.17 Academics

Academics are a heterogeneous group of independent-minded individuals who work, normally, as employees or associates of universities. For the purposes of this characterisation they do not include hybrid scientists, such as government scientists or researchers in corporate laboratories who are included in the corporate and government body characterisations below. They combine research, teaching and administrative responsibilities specialising in a discipline or area of study. They publish their work in media ranging from academic journals and books to popular and social media, and engage with a broad range of parties to share expertise and research findings as well as inform, teach and learn from research. It is unlikely that any academics will have a sole focus on SAI or GE, but will likely use the technologies as framings for their work, bringing the theories, tools and methods from their discipline or area of study to bear on the challenges raised by SAI in the context of their wider interests.

The knowledge academics hold and generate is not absolute and the nature of that knowledge, how and why it is constructed and for what purposes, is important to understand. Roger Pielke's (2007) analysis of the relationship between scientists and policy provides a useful typology of scientists as actors. Pielke's 'pure scientist' detaches themselves from politics and policy. They focus only on research without deliberate consideration of its future use or impact. The 'science arbiter' seeks to answer research questions on behalf of policy and decision makers, but avoids considering normative questions, favouring the development of more open evidence. Pielke's third type, the 'issue advocate', seeks to use scientific evidence intentionally to advance a specific political or policy agenda, with particular outcome objectives in mind. For the issue advocate, values and facts are reflexively intertwined and their values can affect constructions and interpretations of 'facts'. The 'honest broker' scientist seeks to expand or at least clarify the range of choices that evidence suggests might be available for decision-makers. They do this by attempting to integrate knowledge and a broader consideration of possible alternatives.

This characterisation of scientists is helpful in the context of SAI and the stage at which scholarship is operating. Currently there are no ongoing SAI engineering projects with plans to deploy. It is then difficult to see engineering researchers with an interest in SAI deployment as 'pure scientists' in the terms of the typology. Not because they are intentionally, or unintentionally, operating in one of the other modes, but because they are currently not able to undertake pure SAI specific research. However, such researchers could be undertaking pure research that might inform SAI research and development.

Academics from other disciplines are more freely able to engage in SAI research and might therefore be more normally found operating in one of the modes. There are, for example, academics such as Robock (2008) who have taken a very clear path as an issue advocate and sought to steer policy formulation and decision-making through their work. For example, Robock has set out why geoengineering should not be undertaken and continued to support this position publicly.

These differences between scientists are important in the evolution of the governance process because, in the case of a novel technology, they can lead to the creation of spaces within which uncertainty can thrive. Specifically, where there is no reasonable and practical concept of:

- what evidence actually is;
- what different pieces of evidence say or mean in relation to a hypothesis and with what strength they speak; or,
- how to evaluate a hypothesis in the light of all the variable candidate

evidence (Cartwright et al., 2007).

Academics then, in this study, are understood to be actors who can not only inform but also engage in and complicate the governance decision processes from within. Non-academic actors in the governance process may, for example, seek to use depoliticised science as evidence to justify their decisions (regardless of whether they are primarily determined by values and other political agenda). But the act of using academics' evidence can complicate the decision process, widen the scope for conflict, and introduce greater uncertainty and ambiguity depending on the mode within which the academics are working. This is further complicated when interpretations, values or other agenda that other actors bring to bear on academics' evidence reflexively affect, reinforce or change non 'pure scientist' work or behaviour.

5.18 Corporate organisations, including security and defence

Corporate organisations are, or represent those that are, engaged in the economic activity of production and distribution of goods and services with a view to securing profit. Corporate interests have the capacity, and often the freedom, to act creatively, to generate new ideas, approaches and concepts in response to constantly changing economic, social, physical and technological environments. Key to their interests are their capacity to respond to change and challenges, in a consumer-sensitive way and, to protect or enhance their standing with customers. Linked to these concerns are questions about their responsibility towards society, including how they utilise resources and dispose of waste.

Environmental risks are important issues for corporates, particularly where their direct engagement with these, or uncertainty about causal links, exposes them to the threat of reduced profits or public relations liability. SAI is currently too uncertain and contested for large-scale corporate investment. However a number of corporates do engage with GGR research, and there are some small GGR start-up companies. Other corporates are engaging in debates about the governance of SAI.

For example, the Virgin Group launched the 'Virgin Earth Challenge', a $25M prize for a scalable GGR technology, The Gates Foundation has funded geoengineering research, and Microsoft's former technology chief, Nathan Myhrvold, has patented some geoengineering technologies (ETC, 2010). Shell Research has also supported GGR research, part funding an open source initiative, CQuestrate, directed by the head of the Oxford University Geoengineering Programme. In terms of SAI, The Gates Foundation and Virgin have also supported the SRMGI.

Defense and security corporations have an interest in SAI. Security is the condition of being protected from or not exposed to danger, or the risk of danger. Defence describes the mechanisms by which security is provided or protected. More specifically, in the context of climate change, Barnett (2003) describes security as the assurances people have that they will be able to enjoy elements that are important to their survival and well-being. Environmental security was first coined as a term in '*Our Common Future'* in 1987 (Brundtland) after which the argument that environmental change was a security issue for nations and people was increasingly made. In 1988, the *'Changing Atmosphere: Implications for Global Security'* (WMO/OMN) conference brought together scientists and national policymakers who highlighted the security dangers of environmental change. The conference concluded that: 'humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war'.

Depending on how SAI-driven environmental change - and what sorts of change - threatens people, the technology can be considered as a security issue in terms of its physical effects alone. Indeed, Goodell (2010) notes that 'It's not easy to see how a serious geoengineering program could move forward without some degree of military involvement'. SAI raises a number of security agenda that warrant study. For example, as an opportunity for the defence and security industry, the use of SAI as a military weapon, or the threat of its use being adopted as a negotiating tool by, for instance, geographically low-lying nations with a view to encouraging threatened parties to enhance their climate change adaptation and mitigation activities. Further, security concerns about SAI deployment by major states could be a driver of governance engagement. Such a response would be similar to the role played by non-superpower nations in putting pressure on the United States and the Soviet Union to stop their arms race (Eaves, 2015).

To-date, corporates have been, at least publicly, more interested in GGR technologies than SAI. However, this could change and corporates have the capacity to gain influence quickly over, and drive forward, research and development. A decision to develop and/or deploy SAI by a corporate might be taken for at least two reasons. First, because they believe deployment would be beneficial to their public standing. For example, in the case of a serious climate emergency a corporate could gain public support and capital by deploying SAI, particularly if it effectively cooled the climate with no, or comparatively little, collateral damage. Second, corporates dependent on the burning of fossil fuels for their profit or survival, such as oil companies, could decide that it was in their interests to deploy SAI to protect markets and capital assets. Recognition that, in the longer term, corporates may play a role in the future of SAI is reflected in Mulkern (2012) suggesting that the US Federal Government should ban SRM patents to keep ownership of SAI IP and deployment capacity in the public domain.

That security and defence interests are already engaged in the SAI debate, even at this early stage, is apparent from their funding of research in the field. Examples include the Defense Advanced Projects Research Agency, NASA, and the Lawrence Livermore National Laboratory in the United States funding new research (ETC, 2010). More recently the CIA has also been linked to SAI through its financial contributions to a 1-year US National Academy of Sciences geoengineering study (Barkham, 2015).

5.19 Global institutions

Global institutions, or supra-national organisations, are established by multiple national governments under international agreement, bringing nations together with the objective of coordinating collective action at the global level. They generally have some degree of permanence and operate beyond the formal control of national governments through a conference of members or treaty. They are normally staffed by a hierarchically organised group of international civil servants with a mandate and resources within the context of a defined policy area. They give rise to social practices, assign roles to the participants in these practices, and govern these interactions. They constitute important components of the governance systems at multiple levels of social organization, ranging from the local to the global, and play important roles in the administration and management of regimes dealing with a wide range of topics relevant to SAI.

The UN has played a central role in establishing and organising global institutions, hosting many of them and the secretariats. Examples relevant to SAI include:

- the Convention on Biological Diversity;
- the Agreement on Long Range Transboundary Air Pollution;
- the World Metrological Organisation, and,
- the UN Environment Programme (UNEP), many of which have already actively engaged in geoengineering governance debates, as discussed above.

UNEP is the key global environmental institution. It was established following the 1972 Stockholm Conference on the Human Environment, with a remit to support coherent international decision-making processes for environmental governance by providing an international framework and location for environmental politics, creating and maintaining international environmental databases, and establishing a series of environmental agreements. A key criticism of UNEP is that it is a Programme rather than an Agency, meaning it is funded by donations from member states rather than through an allocated budget. States can then influence its policy direction by varying or removing their contributions according to their interests.

The EU is the most important regional supranational organisation in the environmental sphere (Evans, 2012). Unlike the UN, the EU has a legal mandate from its members to protect the environment and deliver sustainable development. It takes forward this responsibility by co-ordinating environmental policy across member states in order to ensure fair economic competition. It issues framework directives, which set common goals but leaves members the space to decide how to meet them. Member states are, however, obliged to implement the directives, and this has made the EU the largest producer of environmental policy in the world (Jordan, 2002). In the wider context of the UN, the EU plays a particularly important role as it votes en-bloc on UN environmental treaty negotiations.

In the context of SAI, the operation of, and interplay between the UN and EU may provide fertile ground for insights into plural SAI governance processes. How the comparatively soft-levered UN governance processes, which move slowly toward establishing agreements that states may or may not choose to sign up to, engage with and affect the SAI process may contrast markedly with the EU's with its capacity to construct binding directives on members. UN member states outside the EU who see value in SAI deployment may, for example, be absent from UN governance processes and choose not to align with any SAI agreements, whilst EU member states may be required not to deploy due to centrally constructed directives or regulations, even if they might otherwise consider it beneficial in their own terms.

5.20 Non-governmental organizations (NGOs) and other independent actors

NGOs are integral to the philosophy of modern governance, which prioritises the inclusion of non-state actors in order to enhance the legitimacy of decisions, and, as such, they play a key role in facilitating collective action within governance processes. NGOs are non-profit, voluntary citizens' groups independent of government or commercial interests, and organized on local, national or international levels. The UN coined the term NGO to differentiate between public-intergovernmental bodies and private international bodies with whom they worked

(Willetts, 2002). NGOs are variable in size and nature and their structures, objectives and governance vary considerably. They are normally task-oriented toward the delivery of a common interest or service; they perform a variety of humanitarian functions, with a focus on bringing citizens' concerns to Governments and wider communities. Key activities include advocacy, monitoring policies and encouraging change or action through the provision of information. They provide analysis and expertise, can act as early warning mechanisms, and help monitor and implement international agreements.

Within the environmental sphere NGOs enjoy varying degrees of autonomy, making them distinct from formal and informal membership organizations. Their objectives and philosophies are diverse. Some are established, for example, in opposition to the politics of governments, whilst others are based on religious principles, broadly humanitarian ethos, or as quasi-consultancy concerns. Some see themselves as engines for radical change; others focus on more gradual change.

Of crucial importance is NGO independence. They are never mandated to work with governments, global institutes or other stakeholders although they collaborate with a full range of diverse actors, where such alignment can help the pursuit of their objectives. They can play important roles in facilitating bottom up and top down communication, between citizens and other actors, making them a very useful conduit in a governance context. NGO's are also in a unique position to share information horizontally, networking between other organizations doing similar work.

In the context of SAI, NGOs could be expected to play a lead role. Historically they have brought environmental issues to the attention of politicians and were important drivers in the transformation of environmentalism from counter culture to formal policy concern (Evans, 2012). Areas where they are expected to be proactive include:

- advocating environmental justice for those likely to be most affected by SAI;

- assessing changes to environmental conditions and promoting compliance with any international or state agreements or legislation;
- agenda setting and policy development with wider communities;
- gathering and analysing information; and,
- performing operational functions.

The progressive communities term offered a useful conceptualisation which suggests that a type of movement is evolving around SAI going beyond understandings described in New Social Movements (NSM) and local actor theories (Pichardo, 1997, Buechler, 2000). NSM theory addressed the new politics of identity and culture that evolved in the late 1960's such as feminism, environmentalism, civil rights, and later, gay rights. These have tended to be broad-based, issue-led movements covering a wide range of agenda, but primarily social and cultural and only, secondarily if at all, political (Castells, 2004). However, progressive communities, as described by phase one interviewees, are social, cultural *and* political. They also differ in that NSMs have tended to focus on post-material issues as opposed to conflicts over material resources, whereas the suggested progressive communities are engaged in both material and cultural or social resources.

In addition, NSMs are characterised as being located and acting within civil society or the cultural sphere rather than instrumental in action with, and in, states. They have little interest in directly challenging the state or international institutes, rather they are regarded as anti-authoritarian and resistant to incorporation with institutions (Scott, 1990). They also tend to focus on single issues, or a limited range of issues. Progressive communities, however, would engage in a wider set of interrelated agenda and seek to penetrate and influence institutions at the state and international levels.

This characterisation of other interested or affected parties also suggests a different kind of actor to those identified in common resources governance theory. Ostrom (1990) suggests that local communities play a key role in environmental governance and that an embeddedness in 'place' rather than the global agenda plays an important role in driving people's engagement in environmental action. The concept of progressive communities suggests that, in a globalised world, citizens' associations concerned with the environment are global as well as local, and that this is reflected in a new approach to environmentalism that is holistic in scope, reaching across geographies and topics, to encompass global environmental agenda that are interlinked. Importantly, it was suggested that these actors engage not only in environmental agenda, but also in the pursuit of a broader set of complementary goals, including protection and enhancement of human rights, social justice and environmental protection. It may be that such actors will engage more comprehensively in debates around SAI, the global commons, and their governance, than the traditional 'environmentalists' described by NSM or commons governance theories.

5.21 Scientific institutions

For the purposes of this characterisation, scientific institutions are representative and promotional bodies, rather than institutes who conduct research themselves. These bodies, such as disciplinary orientated institutes including the Royal Society of Chemistry or the Royal Geographical Society, or generic organisations such as the Academy of Social Sciences, seek to support and promote communication and collaboration between scientists and wider communities. They communicate and discuss the results, value and meanings of science, both within their membership and with the public, civic society and the policy community. They also seek to promote their scientific community and science more broadly, hosting meetings and events, and publishing in a variety of formats. They often provide key support networks for scientists, and becoming a member of a professional society gives a scientist access to a community of peers, from whom they can both learn and seek feedback on their own work.

These institutions play a critical role in fostering scientific progress and are often catalysts for new debates. For example, the Royal Society's report on geoengineering ignited a significant, on-going debate (Shepherd, 2012a).

Institutions often act as 'promotors' of an area of study, or discipline, working at the forefront of public engagement with science to encourage people to engaged with and understand the value of science in daily life. These efforts to open up and explain science and technology, not just by providing a platform for the public to gain access to credible information, but also by seeking to involve them in discovery, innovation and discussions about the future, have the capacity to play a key role in the evolution of governance of SAI and should be expected to be visibly in play during a polycentric governance process which, theory suggests, will occur during SAI appraisal and potential future deployment.

5.22 Government bodies and departments

Central governments are normally organised into separate departments, most headed by a secretary of state (in the UK) or other senior minister. The structure of these departments tends to reflect the allocation of functions, many of which have long-standing traditions and have evolved over time. In the UK, departments are staffed by civil servants, who work to deliver the policies of the government of the day and are expected to be impartial. In some administrations, staff are political appointments, with political motivations. Departments normally have their own budgets that, in Western democracies, are normally voted by a Parliament or other representative body, and departments are normally ultimately accountable to a Parliament, through the relevant departmental minister. In the UK, non-ministerial departments, for example, HM Revenue and Customs, are departments in their own right, usually headed up by a statutory board. They are, however, accountable to Parliament through their sponsoring ministers and have their own budgets, voted directly by Parliament. Where there is a statutory board, appointments are usually made by ministers.

Executive Agencies, such as the Intellectual Property Office or the Environment Agency in the UK, are held within a Government department. They are defined business units headed up by a chief executive (CEO) and carry out executive functions, with policy set by ministers, but with a degree of autonomy from ministers and the main department.

Non-Departmental Public Bodies (NDPB) such as the Research Councils UK (to become part of UK Research and Innovation in 2018) carry out public functions that are better removed from ministerial departments, operating more at 'arm's length'. They have a greater degree of independence that is appropriate for a variety of reasons. For example, to provide independent advice and expertise on technical or scientific issues that is better taken outside the party political arena. NDPBs carry out a wide range of functions such as regulation, advice, investigation, ombudsman services and appeal, funding and health services. They are separate legal entities, and operate more flexibly than executive agencies. They are able to make decisions in an autonomous fashion, enter into contracts, own assets and set their own strategies and delivery plans.

The pluralist theory of governance being examined in this study, suggested by the Bulkeley (2010) consent, consensus and concord model, would suggest that these state bodies would predominantly reflect and further the interests of society in their engagement in the SAI governance process. This is in contrast to state-centred theories that see the state as not being reducible to social interests, but as constituting an autonomous actor (Evans, 2012). In the context of SAI, this theorised pluralism would be reflected in empirical evidence of the role of the state reconfiguring, through the governance process, as it becomes only one of a number of interested or affected parties engaging in SAI governance. This proposition will be explored in the study.

5.23 Conducting the main phase

Prior to commencing fieldwork, ethics approval for the main phase of the study was secured from the Ethics Committee (Ethics number 17683 see Annex 2).

Interview invitations were sent to over 120 named individuals over a five month period (in 2015). Each invitation was bespoke and aligned with any known interests of the individual and reflected their institution or corporation’s interests where appropriate. Careful attention was paid to ensure prospective interviewees were aware that their contribution would be in confidence and anonymous and that the study was independent. The participant information sheet, consent form and other material provided to invitees and interviewees are also provided in Appendices A and B to Annex 2.

Interviews were undertaken during the period November 2015 to May 2016. They were conducted face-to-face, by telephone, or on-line, depending on participants' preferences and location. In line with the pilot phase, the interviews were transcribed in full and placed in NVivo for purposes of analysis.

5.24 Testing the theoretical framework

Drawing from the Renn and Bulkeley models discussed in Chapter 4, a series of expectations are offered against which the interview evidence is contrasted to explore if interviewees' thoughts aligned with the theoretical expectations. There are two *a priori* positions that must be satisfied before the theories can be explored in full. These relate to how risk is characterised and whether intolerable risks can become tolerable.

Underpinning the decision to use the Renn (2008) risk management model lies recognition of the insight that risk is characterised, interpreted and acted on differently by different groups, actors, and the public, and that these variations can have significant effects on the governance and uptake of new technologies (Bubela et al., 2012). For example, polarisations of views between actors where issues of trust, confidence, ethics, perceptions of procedural fairness and, in some cases, ideologically based framings of a technology as inherently hazardous have affected the evolution of governance of nanotechnology and synthetic biology (Siegrist et al., 2012, Wynne, 2001, Tait, 2012, Poortinga and Pidgeon, 2005, Pidgeon et al., 2012). If such differential risk characterisations and assessments, as a corner stone of the theoretical framework, do not exist within the case of SAI the use of the Renn theory would be inappropriate. This then is the first of two *a priori* questions that are explored in the analysis. It was addressed through the question to interviewees 'How would you characterise risk?'

The second *a priori* question relates to tolerability. The Renn model suggests three risk management strategies, or routes to minimise risk and allow progress through deliberate measures and actions to arrive at mediated positions regarding deployment. In each option SAI must be able to move from a risk state of intolerability to tolerability. Should a risk remain intolerable, the only outcome would be joint strategic decisions not to act, as expressed in Renn's (2008) option three. In this circumstance the Precautionary Principle would be enforced by international law and investment in the development of substitutes of SAI, for example, GGR would be expected. It is important then, to explore whether participants believed an intolerable risk could ever become tolerable. Interviewees were therefore asked 'Can an intolerable risk become tolerable?'

Following an analysis of the first *a priori* questions, the material is then explored to establish whether the interviewees framed the risks of SAI in line with the Pythia or another class. Having identified in which risk class participants situated SAI, how interviewees expected SAI risk management to proceed, and whether that aligned with the expectations of the Pythia is examined.

How subjects believed knowledge would be developed, why and whether the expected decision-making processes align or not with the expectations of the model, is then examined. This establishes whether deployment decisions might, as theorised, be taken in the light of comprehensive measures to raise consciousness and confidence or not. Finally, the risk theory analysis examines interviewees' positions regarding whether deployment might be increasingly tolerable over time, in response to risk management measures.

Having concluded the risk theory analysis, the governance model is explored. First, this explores what sort of governance systems might evolve, how and why, and, second what the role of uncertainty in the governance process will be, in particular in relation to opening up or closing down the governance process. In the light of this, the role of consensus, consent and concord in the governance process is tested to understand how authority might be given, taken or negotiated.

5.25 Presenting interviewees' contributions

The participants in this study were senior stakeholders with well-developed thinking about the issues at hand. They had all thought about global scale risk governance in particular and many were high profile workers and thinkers on geoengineering and SAI. They have therefore been given agency in the reporting of findings through the use of quotations allowing the interviewees to speak for themselves alongside the interpretation and analysis. This, it is hoped, allows the reader to judge for themselves the intentions of the interviewees. The reader is therefore encouraged to read and reflect on the quotations, to hear their voices and use those insights. In some cases, quotations are long, but those longer extracts express complex challenging ideas that required space to fully express. The names given alongside the quotes are pseudonyms, not the original speakers names - in the interest of protecting anonymity and confidentiality.

5.26 Conclusion

Semi-structured interviews were the most appropriate research method available to secure the insights required. They opened up access to divergent perspectives on SAI governance and were expected to be sufficiently flexible to avoid closing down unnecessarily. A number of interested or affected parties were included in the sample, as suggested by the literature and theoretical expectations, and these have been characterised.

A pilot study was conducted to test the method and its operationalisation and, with adjustments from lessons learnt, a revised set of core questions was constructed and a second semi-structured interview designed. The pilot study interviews were analysed using deductive and inductive analysis, and in the light of that process a deductive approach is used in the main phase.

A main phase sample was drawn up and 30 interviews were undertaken. The findings are presented in Chapters 6, 7 and 8.

CHAPTER 6 – ANALYSIS OF FIT TO THE RISK FRAMEWORK

6.0 Chapter overview

This chapter describes the nature of the sample achieved and the characteristics of the respondents. Subsequently, it focuses on the fit of the Renn risk model, firstly addressing two *a priori* questions: how the interviewees interpreted the meaning of risk; and, whether they believed an intolerable risk could become tolerable. This reveals that participants framed climate emergencies as a key issue in their understandings of how risk management might play out and this issue is explored in some depth.

An analysis of the interview evidence in section 4.8 demonstrates that SAI is a good fit to the Pythia risk class in the Renn typology, as theorised. In the light of this, respondents' perspectives on how SAI risks might be managed are explored and the interview evidence indicates these views align with the model's five risk management strategies.

The chapter concludes by suggesting that open and discursive public risk debates may occur, in line with the theoretical expectations, and that they could lead to risk management acquiescence such that SAI deployment could, over time, become tolerable.

6.1 The sample

Thirty semi-structured interviews of actors, as explored in section 5.16, identified in the literature and suggested by the theoretical framework, were conducted. To achieve the sample, 121 named individuals were contacted with bespoke requests to participate in the study. In total 32 agreed to participate, although two of those had to withdraw. The mix of interviewees by actor group is shown in Table 6.1.

Of the 89 who declined to participate, 12 failed to respond to the invitation or a reminder and, 39 declined due to time constraints. The remaining chose not to participate because they felt they had insufficient knowledge about SRM (N=14), or their institute or organisation had done little strategic thinking about the topic (N=12). The remaining 12 had taken a strategic decision not to engage in SRM and SAI debates for various reasons, for example, those in the corporate sector did not expect SAI would influence their operational planning during their planning period.

Table 6.1 Interviewee sample by group

GROUP	NUMBER COMPLETED
Global Institute	3
Government Body or Department	5
Non-Governmental Organisations	5
Social scientist	5
Corporate including security and defence	4
Scientific Institutions	3
Natural Scientists	5

Because the names and institutional affiliations of invitees and participants are subject to the confidentiality and anonymity constraints placed on the study by the terms of the ethics approval, they cannot be disclosed. The names quoted in the following analysis are therefore not the interviewees' names, nor necessarily gender, but randomly selected pseudonyms that bear no relation to the subjects' actual names. Details of how confidentiality and anonymity were protected are shown in the research ethics details at Annex 2.

As per the pilot phase, the interviews were recorded and transcribed. NVivo software was used during analysis.

6.2 Characteristics of the interviewees

Only five interviewees are women, although 23 were invited to participate. Whilst there is evidence that women are underrepresented in the geoengineering field (Buck et al., 2013) it is not possible to conclude whether this sample underrepresents the current participation of senior women in the issue.

All of the academics who contributed are recognised in the fields of environmental risk governance, SRM or environmental adaptation and mitigation. Eight of the ten have published on SRM in peer-reviewed academic journals, five from the natural and three from the social sciences respectively. The government department subjects include an African state employee and senior staff working at director level in different UK departments. Three of the NGO interviewees are from global organisations and based overseas and the corporate representatives come from global corporations, including the defence industry. The standing of interviewees is high and includes previous state and Presidential advisors, Chief Scientific Advisors or their overseas equivalent, and directors of global companies from South East Asia, Africa, Europe, South and North America.

Seven of the interviews were conducted on a face-to-face basis, nine via online video and the remaining 14 by telephone. Interviews lasted in the order of an hour, although two were less than 30 minutes and four lasted over an hour. One ran for two hours split over two sessions. The majority of the respondents required very little prompting and spoke freely during the interviews. This provides evidence that the decision to interview senior stakeholders was appropriate. Less experienced interviewees may have been less able to fulfil the objectives, set out in the Chapter 5, which required that the interviews systematically and reflexively elicited perspectives on what SAI risk management and governance might look like, and how it could operate. Although the respondents had all spent some time working on, or thinking about SAI, they did not represent a group or collection of likeminded SAI activists. So, whilst they had considered SAI, their contributions are not a reflection of groupthink (the practice of thinking or making decisions as a group resulting in unchallenged or poor decisions). The quality and complexity of the interviewees' contributions give confidence that the perspectives were valuable, meaningful and deliberative. However, the generalisation of the findings must be considered carefully given that the technology is as yet not specified, nor its implications fully understood.

6.3 Analysis – testing the risk management theory

The data collected through the semi-structured interviews are now used to test the risk management theoretical framings using the Renn model (2008). To recap, the model recognises and accounts for uncertainty and ambiguity through a range of concepts of risk that include a set of nine attributes to help inform risk characterisation. Critically, it recognises the importance of perceptions of risk and their effects on actors' risk assessments. As introduced in Chapter 4, the model distils the nine attributes into six risk classes, Damocles, Cyclops, Pythia, Pandora, Cassandra and Medusa, and fits these to three categories of risk management for which Renn proposes different risk management strategies.

Initially the two prerequisite *a priori* requirements of the Renn model must first be tested. These are: whether there are differential characterisations and understandings of risks amongst actors; and, if they believe it is possible for intolerable risks to become tolerable. Should these prerequisites not be satisfied, the theoretical framework would be unable to inform how SAI might be governed, aside from suggesting that internationally binding rules to ban SAI will be constructed with very little or no dissent and that these would be fully binding in perpetuity by common committed agreement.

6.4 The existence of differential risk characterisations

The theoretical framework suggests that characterisations of risk will vary across types of actor and interested and affected parties such as those groups included in the sample. Interviewees were asked 'How would you characterise risk?'. Two respondents felt they were unable to provide a sufficiently complete answer. The remaining 28 participants initially characterised it in utilitarian terms, describing it as a quantifiable concept based on probability in the context of uncertainty. However, beyond this they all discussed a broad range of more complex risk concepts including political, scientific, social and cultural risk perceptions. Some linked these to macro questions about democratic plurality, geopolitics and resilience. James, who works in the government sector, revealed some of these complexities when he said:

> *'There is a rather conventional definition of risk: the likelihood of a harmful effect happening. Well I would put a lot of weight on irreversibility, something you couldn't put a stop to, or even if you did put a stop to it, you couldn't -- you couldn't change what was happening because of what you'd already done. I would characterise risk in the sense of the partial knowledge that we have about the Earth system too.*
>
> *And, ambiguity as well because there will be very different world views about the whole morality of you know, if the analogy that's often used in other areas, playing God with the Earth's atmospheric system and related systems.*
>
> *Then, obviously, huge swathes of ignorance, just not knowing what might happen, what effects there might be, something completely... What if something suddenly ended up interfering with photosynthesis, for example? I think there's something that's about whether this is right or wrong. And if you're a utilitarian, you'd say: 'Well, if the benefits greatly outweigh the costs, then it's right. If the probable benefits greatly outweigh the probable costs, the 'risks.' But if you're a deontologist you might say: 'Well it's just not right to do this. It's wrong, whatever the consequences, it's wrong to do these sorts of experiments with planetary systems. So you shouldn't do it, and I think there's also a construction of 'We shouldn't do this because it will enable us to go on being bad', and being bad has many types of social, cultural and faith risk problems doesn't it?'.* James - the government sector.

None suggested risk was solely a quantitative assessment that could be tested and resolved empirically. Three did explicitly note that attempting to include complex understandings of the characteristics of risk into SAI governance debates makes for opacity that may frustrate communication. For example Sabian, a social scientist noted:

> *'If you read the rhetorical gymnastics that everybody has to go through when discussing this: 'Oh not forecasts, not predictions, projections. Oh, not projections, here are scenarios'. What does that mean? You know, 'Take the insights, not the numbers'. What does that mean?*
>
> *I think the word 'speculation' needs to be brought back into respectable discourse on risk. Speculation scenario exercises.'* Sabian – a social scientist.

In the light of interviewees' consistently various characterisations of risk that included, among others, reference to incertitude, uncertainty and opacity created by inaccurate reporting, the first prerequisite of the risk model can be accepted. The space this variation creates as a location for convergence: or consensus, consent or concord, is further explored in Chapter 7.

6.5 Fluidity of tolerability

The second prerequisite is that there can be conditions under which an intolerable risk can become tolerable. Unanimously, interviewees said that an intolerable risk could become tolerable. This was for various reasons, including, in particular, that climate 'emergencies' or shocks would shift perspectives on relative risk, meaning SAI could become tolerable if the threat of another hazard were so great as to diminish the threat or risk of SAI. Other comments reflected on nuclear weapons and the shift from intolerability from the 1960s to present day. Brian and Geoffrey, physical and social scientists respectively, said:

> *'Yes, look at nuclear weapons that have existed for seventy years. People don't worry about it anymore, it's very frustrating, even though we could have a nuclear winter tomorrow where everybody in the world would starve to death if the US actually used their used their existing weapons.'* Brian – a physical scientist.

> *We've seen that. The risk of nuclear annihilation hasn't gone away but we hardly ever talk about it. I'm of a generation that grew up when we used to do nuclear attack civil defence drills. Now it's never discussed.'* Geoffrey – a social scientist.

The interviewees did not directly discuss notions of acceptable risk as a utilitarian calculus of cost and benefit. The contributions were in fact focused on questions about societal perceptions of what is an intolerable amount to pay in non-financial terms, with some recognising that the evidence and financial allocations used in quantitative approaches are often, if not always, based on false premise, uncertainty and even ignorance. A few of the participants discussed a sliding scale of tolerability mentioning that different societies will have different attitudes to what is and is not acceptable, reflecting Stirling's (2008) propositions regarding notions of normative ambiguity.

These interviewees' positions stand in contrast to practice in the policy world. Here, Jasanoff and Kim (2009) suggest, the language of toleration, or tolerability, is often translated into the language of utilitarianism through the application of incentives to some but not all interested and affected parties in multilevel governance situations. Under these circumstances, little will remain intolerable if policy makers are minded to be flexible with evidence and encouragements, to shift the cost benefit calculus in favour of their own strategic objectives. South Korean policymaking approaches to nuclear deployment are an appropriate empirical example of this given that 11 interviewees specifically discussed nuclear as an analogy. The South Korean government consulted on nuclear deployment. A national anti-nuclear movement was born but the government offered local communities incentives to accept generators and waste dumps, off-setting those communities' cost benefit assessments and by-passing wider national intolerance of nuclear such that it was deployed (Jasanoff and Kim, 2009). Whether interviewees' suggestion that this approach will not be adopted in relation to SAI is an interesting proposition, and would benefit from further research.

6.6 Climate emergency framing

The interviewees spontaneously discussed, at length on 36 occasions, how tolerability could shift in response to natural processes, including emergencies and extreme events. In addition, extreme event clusters were discussed by 17 respondents on 21 separate occasions. This is noteworthy given they were not asked direct questions about emergency or extreme event framings. Of the 19 who discussed extreme events, six did not discuss emergencies. Events described included increased frequency of tropical storms, severe drought, crop failure or flooding leading to multiple deaths and large-scale migration.

The 'emergency' framing as a justifying rationale, or explanatory reason, for why SAI might be deployed has been debated at length in the geoengineering literature (Crutzen, 2006b, Victor et al., 2009a, Goldblatt and Watson, 2012). However, it has generally faded from the conversation in the light of social scientists' concerns about what would constitute an emergency, how it would be identified, who would declare such an emergency, and what the implications of such an emergency would be (Heyward and Rayner, 2013). Gardiner (2010), for example, has set out a wide-ranging critique of SAI as an emergency option in the face of an imminent catastrophe. Given the prominence it has amongst this group of interviewees, it is now explored in more detail.

There is no clearly defined definition or description of what a climate emergency might constitute. However, two physical events or phenomena are frequently suggested in the SAI literature, namely tipping points and runaway GHG emissions (Lenton et al., 2008).

A climate tipping point is described as a point in time where a planetary subsystem switches into a substantively different state. A number of such points have been identified in past records where paleoclimate data demonstrates many instances of abrupt, non-linear shifts on the climate system. Examples include Heinrich events where extreme rapid declines in temperature are recorded or Dansgaard-Oescher events of sudden, short-lived temperature increases.

Suggested contemporary climate change tipping points include:

- decreases in the arctic ozone column;
- thawing of Siberian permafrost;
- the extent of Arctic sea ice, the volume of marine methane hydrates;
- the volume of the Greenland and West Antarctic ice sheets; and,
- increases in the El Nino Southern Oscillation amplitude (Lenton et al., 2008).

However, if such tipping points might rationalise a choice to deploy SAI they must be likely to occur and there is currently scant evidence of such events occurring in the near future. The IPCC Fifth Working Group Report (2013) noted that there are no known potential tipping points that are likely to be simultaneously abrupt, irreversible, and likely to be crossed in the current century. In addition, research on related theories of planetary tipping points have also seriously undermined tipping point claims. Even those working on the theory make clear the limitations of their models, and the lack of robust evidence to inform them (Brook et al., 2013).

Even if tipping points were recognised as possible and probable, this does not immediately mean that they should or must be avoided. Any steps taken to avert a possible catastrophe, which may or may not happen, has, for example, the potential to obscure very real and severe problems caused by gradual anthropogenic climate change that are already damaging the world's poorest countries.

The second global emergency scenario discussed by Lenton (2008) was 'runaway GHG emissions', described as where the atmosphere would become super-saturated with GHGs and a hot and water-vapour-rich atmosphere would then limit the emission of thermal radiation to space, causing runaway warming. This would cause positive feedbacks potentially leading to the boiling away of oceans and the extinction of life on Earth. However, whilst this scenario will inevitably play out in approximately 2 billion years' time as solar luminosity increases, Goldblatt and Watson (2012) have shown it is unlikely to be possible, even in principle, for anthropocentric emissions to trigger a full 'runaway greenhouse effect'. They note, as an interesting aside, that solutions considerably beyond humanity's current engineering capability, may be available to counter the brightening of the Sun in the future, including altering the orbit of an asteroid to transfer orbital energy from Jupiter to Earth thereby moving the Earth's orbit in a process of 'Astronomical Engineering'.

Evidence about the likelihood of tipping point emergencies or runaway GHG emissions, then, provides a weak foundation from which to argue the case for SAI. There is currently no robust evidence to demonstrate a cataclysmic 'moment in time' at which the climate switches abruptly from its current state to a markedly more dangerous, damaging one to which humanity is unable to adapt without global crisis and massive adaptation is likely to arrive. During the fieldwork, two interviewees explicitly recognised this, noting that:

> *'I did not use the word 'emergency' and there is no such thing as a planetary emergency. An emergency is an artificial construct; it's not a physical thing. There was a great talk at the climate engineering conference last year in Berlin about climate emergencies, people were showing headline after headline after headline that said 'climate emergency' for the past twenty years. You can write a headline that says 'climate emergency', you can do it, but there's no real meaning to it.'* Brian - a physical scientist.

> *'Realistically, I think those views are part of the hype in this conversation where people can kind of publish on that, and, as you know, bad news sells. So I think that's kind of a silly. I just don't think that there's much merit to that in real life.'* Bill - the corporate sector.

Whilst the emergency framing of geoengineering has not gone without scrutiny, it clearly retains some ground amongst the interviewees and remains an underlying narrative within their thinking. This is reflected in others' research; the Tyndall Centre, for example, found that 'climate emergency' was the joint most-common frame in expert appraisals of geoengineering (Bellamy et al., 2012). In addition, Markuson and colleagues noted that whilst the term 'emergency' may not be used explicitly, terms such as 'dangerous', 'urgent' and 'abrupt' climate change are commonly used in the scientific and popular literature to suggest similar concepts (Markusson et al., 2014). This, then, suggests that emergency framings may still provide a rationale for deployment, dependent on how an emergency is characterised.

Interestingly, the interviewees in this study used nuanced emergency framings. They discussed events or moments in time that had a sense of urgency and immediacy, required a rapid response, had a sense of necessity, and carried a significant chance of harm or loss. For some, for example, emergencies had the characteristics of clusters of extreme events such as drought, flooding and food shortage, or sudden temperature spikes. For others they were regional, or nation-state scale extreme events or clusters of extreme events that might prompt unilateral or regional deployment or emergency policy constructions. The types of emergency events mentioned by participants are listed in Table 6.2.

Table 6.2 Extreme events or emergencies mentioned as potential drivers of deployment

EXTREME EVENT	N
Extreme shifts in precipitation patterns	5
Ozone depletion	5
Food crop failure	4
Disruptions to monsoon	4
Negative effects on water security	1

The inclusion of ozone depletion and SAI as a protective measure in this list is interesting given a key risk of deployment of sulphate SAI is a potentially dangerous reduction in ozone, not a protective influence.

Examples of interviewees' uncertainty about the nature of events that might construe an emergency and its characteristics, included:

'I think that if millions of people are dying, I think that is definitely an emergency. You can't call it anything else. It is an emergency. I mean, whether you can pin it to climate change is something else, but probably if it was that number of people, there would be a lot of pressure to say 'Yes, it is due to climate change. We're going to do something about moderating the climate'' Freddie - a physical scientist.

'I think if a state of emergency was declared in a number of different places as a result of climate change, I mean again, it's much more likely to be as a result of localised, in time and space, pollution, rather than, I think, climate change, but repetitive crop failures could well cause an emergency to be recognised.' Skye - the government sector.

'Well there's not going to be a single emergency, is there? So it's difficult to know what the emergency would look like you know. We're staring at an El Nino, which is catastrophic. We're looking at terrible droughts in southern Africa, but do politicians regard that as an emergency? I don't see it. And it's certainly not on number one on their radar screen.' Bob – from a scientific institution.

Other interviewees talked about emergency not in terms of an imminent physical environmental effect but in more complex terms. Robert, for example, described it as a narrative tool that might be mainstreamed into the climate policy community if that community fails to deliver the conventional mitigation measures it has constructed in fora such as the UNFCCC 'in time'. Virgil suggested SAI might be used as a pre-emptive strike against an emergency that may happen in the future rather than one that was expected or imminent.

'So, say we come back after COP21, we come back in ten years so we'd had two five year cycles, and the answer is 'It's just not working. It's just not getting anywhere'. You know, we really have a couple of years and cutting carbon emissions isn't going to do anymore because the carbon dioxide is already up

there, you know, we're going to have a runaway effect unless we do something right now. You can just about imagine that the pressure would become so intense that people would turn to those (i.e., SAI) *kinds of solutions.'* Robert - the government sector.

'Deployed early you could enormously suppress the chances of experiencing climate emergency. So one might deploy SRM to stop a climate emergency ever happening in the first place. So in that sense, it's an emergency response. I don't buy into the idea that you'll spot an emergency happening and then turn it on.' Virgil - from a scientific institution.

The use of an emergency framing to talk about SAI deployment is clearly complex. Whether an event is described as 'an emergency' is not a technical decision but rather it depends on how events are observed and experienced, and how people are affected by them. Interviewees suggested emergencies are individually unique social constructs and not quantitatively constructed empirical moments in time.

There is increased complexity given the nature of climate change related emergencies. High impact events labelled as emergencies in the ways suggested by the interviewees, such as harvest failures and extreme flooding, may be blamed on climate change even in the absence of causal evidence. Attributing such individual events is, however, a highly contested area and attributing the social effects of those events to climate change is even more complex and may be impossible.

This study, then, suggests that it is critical to understand, when discussing climate emergency in the context of SAI, that the key questions are not 'what is a climate emergency', 'or will an emergency happen', but rather how notions of emergency are constructed. This question was explicitly explored by three respondents and was explored in some detail by Ian, a physical scientist:

'Much of the use of the emergency framing in discussions over climate engineering has presumed or assumed away the difficulties of who perceives an emergency, how broad and diverse a set of people or political actors

perceive an emergency, and how broad and easy is the agreement on the appropriate response to the emergency. It's been a standard trope of the debate for about eight years that some people say 'Acts fast. Use it in an emergency' and then others say 'But what counts as an emergency? According to whom? And who decides?' and then it stops and that criticism I think is appropriate, and yet the criticism mainly targets the naïve presumption that there could be a rapidly emergent and simple global consensus on the character and the appropriate response to an emergency, and that indeed is something that it's fair game to be quite critical about. I think it's far more plausible to imagine a set of climate changes underway in a particular nation or region that lead to extremes of citizen alarm and political alarm in that nation or region such that they perceive they're facing a climate emergency, whether or not people in other parts of the world do. And so to (some) extent that is emergency framing'. Ian – a physical scientist.

6.7 What might an emergency framing mean for governance?

The term emergency implies a situation that poses an immediate risk that arises at very short notice and a rapid response is required, and some interviewees did consider what might happen in an existentialist emergency. For example, Martin from an NGO and Phil, who works in a global institution said:

'Until people's very existence is threatened, it's going to be really hard to get people to respond in any concerted way and so, like OK, now I'm finally answering your question, from my point of view, geoengineering governance is likely to be crisis governance, and very little more'. Martin - from an NGO.

'People will be able to kind of go: "This is a war situation". Right? This is an existential threat. If we do not do something … so and that would be a good example actually, if we could just hold back the solar forcing for a while by an amount, then that gives us breathing space to fix some of the underlying

problems. Then people will go "What took you so long?"' Phil - from a global institution.

However, whilst the likelihood of clusters of extreme events is expected to increase, there are no immediate expectations that extreme events will reach any emergency thresholds. There is, then, no rational justification for developing SAI and its governance within an emergency frame. However, if SAI were to be used in an emergency planning scenario in the expectation of actual use, the framing would nonetheless affect the social appraisal of the technology within which those with incumbent interests associated with emergency framings would likely be instrumentally assisted. The emergency framing could then be used as a top-down legitimisation of the appraisal processes, driving the construction of policy questions, boundary remits of institutions, and the remits and memberships of committees, and might invite authoritarian tendencies.

6.8 Theoretical prerequisites

Two conditions needed to be met before adopting the theoretical framework. Firstly, that risk is viewed differentially by various actors and, secondly, that it is possible for an intolerable risk to become tolerable, under some circumstances. These two key questions were explicitly explored during the interviews and both requirements have been met, suggesting the theoretical framework can appropriately be applied to further explore SAI risk governance. The discussion about how tolerability may be reached highlighted that many interviewees thought in terms of emergency or shock scenarios in relation to what could drive deployment in due course. This was explored in the context of SAI and broader geoengineering literature debates that have tended to dismiss such framings.

The remaining elements of the theoretical framework are now explored.

6.9 Alignments of risk framings to the Renn model

Interviewees' perspectives about the potential risks of SAI are now mapped against

Renn's six risk typologies to verify where SAI is best situated. In the light of this, whether respondents expect SAI to be governed in a fashion that aligns with the theoretical expectations of the risk class is discussed.

In the theoretical analysis of SAI, it is suggested that it would fall into the Pythia class. This class is characterised as a risk where there is uncertainty about the probability of occurrence, the extent of damage, the allocation of cause and effect, and how damage may manifest itself in the context of uncertainty due to high complexity. Interviewees' positions are now situated within the risk typologies to test the theoretical expectation that SAI is best described as a Pythia risk.

Five participants recognised risks that sit in the Damocles class. Specifically, they discussed the possibility of SAI being weaponised and used as a military tool or as an intervention that could lead to military conflict (see Table 6.3).

Table 6.3 Mapping SAI risks against Renn's Damocles risk class

RISK CLASS	CLASS DESCRIPTION	POTENTIAL RISKS IDENTIFIED THAT ALIGN TO CLASS
Damocles	A very high potential for damage but a very low probability of occurrence.	Potential for military use.

Gemma, a social scientist for, example said:

> '*I suppose it could be weaponised. But it could certainly, it seems to me, lead to conflict with more conventional weapons. So you could see, just like, you know, if a state might threaten to, no indeed not threaten, states have gone and bombed other people's nuclear reprocessing plants. They might want to come and destroy your airfield where you're getting ready to go and shove aerosols into the atmosphere.*
>
> *I wonder if it could also, at some point, be used in some hideous kind of blackmail, ransom-type thing. Some group or state saying, 'We are ready to do this. You don't know where we are, we're going up there, unless you do such-*

and-such, we're going up there to put this stuff in the atmosphere'. Gemma – a social scientist.

Such risks are allocated to the Damocles class because, whilst a military intervention with SAI would be purposefully aimed at causing the maximum damage, the likelihood of occurrence is low. For example, global security mechanisms such as the UN Security Council, and the ease with which deployment delivery systems could be neutralised minimise the capacity for deployment, and particularly, deployment that would have meaningful climate effects.

The Cyclops class includes risks where the probability of occurrence is largely uncertain, but the maximum damage can be estimated. Six interviewees discussed the risk of SAI leading to environmental effects, as a result of a reduction in planned or current climate change mitigation measures leading to changes in ecosystems, ocean acidity and the global energy balance. Whether mitigation scenarios would change after deployment is uncertain. However, it is possible to estimate the damage that may be caused by increasing emissions using climate modelling tools that provide a likelihood assessment of the maximum, or worst case, scenario. It is fitting, then, that these risks are linked to the Cyclops class (see Table 6.4).

Table 6.4 Mapping SAI risks against Renn's Cyclops risk class

RISK CLASS	CLASS DESCRIPTION	POTENTIAL RISKS IDENTIFIED THAT ALIGN TO CLASS
Cyclops	The probability of occurrence is largely uncertain, but the maximum damage can be estimated.	Diminished climate change mitigation – unabated GHG emissions measurable effects on ecosystems, oceans and global energy balance.

The large majority of interviewees' deployment risk comments aligned with the Pythia class where risks are uncertain, and the probability of their coming to fruition, the extent of damage caused and how that might be manifested are unknown due to high complexity. Thirty-two examples of risks that could be characterised in this way were given with 11 specifically discussing the implications of 'unknown unknowns' that reflect a condition of ignorance about SAI (see Table 6.5). Interviewees' comments show some recognition that it would be impossible to predict potential futures in a risk context. For example, Freddie, a physical scientist said:

> '*The biggest uncertainty is the unknown unknowns, where we know the models are not perfect, we know they get things wrong, and they know things happen that we don't predict. Donald Rumsfeld was so right. It's the unknown unknowns that bugger things up. It isn't the only thing that buggers things up, but it's the big 'Oh shit!'* Freddie – a physical scientist.

Table 6.5 Mapping SAI risks against Renn's Pythia risk class

RISK CLASS	CLASS DESCRIPTION	POTENTIAL RISKS IDENTIFIED THAT ALIGN TO CLASS
Pythia	Uncertain risks, where the probability of occurrence, the extent of damage, the allocation and the way in which the damage manifests itself is unknown due to high complexity.	Unexpected impacts and implications, 'unknown unknowns' with limited contested evidence and research undermining capacity to identify any risks.
		Ozone depletion - increased ultra-violet flux to Earth's surface.
		Effects on regional climate - an inability to distinguish effects of deployment from background climate and weather events. Planetary and localised drought or other rainfall perturbation including effects on the monsoon, food production and financial loss. Uncertain negative effects on water security.
		Deployment is used in response to an 'emergency' but fails to 'save' humanity.
		Bounce back damage following abrupt termination.

Pandora class risks are similar to Pythia risks aside from the possibility of the probability of risks being derived from credible assumptions. As noted in the theoretical framework, both Pandora and Pythia classes are located under the same 'Precautionary' risk management strategy, meaning the expected risk management approach to both will be the same. However, differentiation between the two classes is important in terms of the focus of risk management. The construction of credible assumptions in relation to SAI is challenging, given the lack of basic research insight previously discussed. However, one risk discussed by four interviewees does appear to meet the class description, that there will be social and political disruption, but how this might be manifest will be dependent on how SAI debate evolves. The Pandora risks are mapped in Table 6.6.

Table 6.6 Mapping SAI risks against Renn's Pandora risk class

RISK CLASS	CLASS DESCRIPTION	POTENTIAL RISKS IDENTIFIED THAT ALIGN TO CLASS
Pandora	Uncertainty in probability of occurrence, the extent of damage and its manifestation where the probability is derived from credible assumptions	Social and political disruption – the extent and potential damage uncertain dependent on how deployment is managed.

One interviewee suggested deployment would be preceded by detailed research undertaken in the context of the Precautionary Principle. They suggested this work would provide clear evidence about potential risks and these would be addressed prior to deployment to the satisfaction of the community. This expectation fits neatly with the Cassandra risk class, as detailed in Table 6.7. None of the other interviewees' risk conversations aligned with the class.

Table 6.7 Mapping SAI risks against Renn's Cassandra risk class

RISK CLASS	CLASS DESCRIPTION	POTENTIAL RISKS IDENTIFIED THAT ALIGN TO CLASS
Cassandra	Probability of occurrence and extent of damage are known, but there is no imminent societal concern because damage will only occur in the future. There is a high degree of delay between the initial event and the impact of the damage.	Risk minimal if quality research is conducted prior to deployment and Precautionary Principle applied.

The final risk class, Medusa captures low probability, low damage events that can raise public concern amongst a large number of people that might be affected.

Two interviewees, including Skye from a government body, mentioned that SAI could lead to global whitening of the sky:

'There are also other negative effects that have been hypothesised that would be associated with the technology, such as changing the colour of the sky, the size and clarity of the sun's discus in the sky, the notion that if you put a lot of aerosols in there, you're going to have a lot of light scattering, and therefore you're not going to see the sun in the same way. So there's sorts of perhaps more aesthetic but nevertheless not trivial risks.' Skye - the government sector.

Whilst that is less likely to cause direct harm than other risks discussed by the interviewees, and could help increase food productivity, it would affect everybody and harmful effects could be very difficult to attribute. It therefore fits the Medusa class shown in Table 6.8.

Table 6.8 Mapping SAI risks against Renn's Medusa risk class

RISK CLASS	CLASS DESCRIPTION	POTENTIAL RISKS THAT ALIGN TO CLASS
Medusa	Low probability and low damage events, which nonetheless cause considerable concern for people. Often a large number of people are affected by these risks, but harmful results cannot be proven scientifically.	Global whitening - 'no more blue skies'.

6.10 Overview of fit to class

The interview evidence and analysis above gives some confidence that SAI could be appropriately classified as a Pythia class risk. Interviewees clearly expressed uncertainty about the probability of occurrence, the extent of damage and its manifestation and these views were based on assumptions rather than any concluded detailed appraisal of an intervention.

Having identified SAI risks as framed in a way that aligns with Renn's Pythia class, the interview evidence is now examined to test if the risk management approaches expected by interviewees align with Renn's Pythia risk strategy.

6.11 Will actions align with Pythia risk class model?

SAI, as a Pythia class risk with capacity to create highly persistent damage is situated in the 'unacceptable range' of the Renn model (as shown in Figure 4.2). As discussed, the model suggests five strategies for such a risk:

- taking a strategic decision not to act and to implement the Precautionary Principle;
- seeking to develop substitutes to achieve similar outcomes with less risk;
- improving knowledge;
- where appropriate, taking measures for containment and reduction; and,
- developing emergency management plans and tools.

If these are present, or expected, the model suggests the risk, in this case SAI, can be managed such that it becomes tolerable and might be deployed. If these strategies cannot be delivered, SAI would move into the 'prohibited area' and not pursued. The interviewees' thinking about SAI risk management and the extent to which they align with the theoretical expectations is now explored, taking each risk management strategy in turn.

6.12 Strategic decisions not to act and to implement the Precautionary Principle

Eleven participants referenced the Precautionary Principle in relation to the use of SAI directly. Some suggested it should be applied because SAI is too dangerous, whilst others saw the use of the Principle not as a permanent constraint, but, rather, a tool to buy time to resolve uncertainties, as suggested by the model. Phil, an interviewee from a global institution, took this view, saying:

> *'There should be a path that will be the application of the Precautionary Principle until the uncertainties can be definitively resolved through the application of various methodologies, particularly research of course.'* Phil - from a global institution.

Chapter 3 explored Hartzell-Nichols' (2012) double jeopardy issues associated with the use of the Principle in response to SAI. This suggests that the Principle may, at first glance, seem to permit SAI deployment and research as a precautionary measure against high impact climate change. However, in the context of uncertainty about the risks of SAI it may be inappropriate to deploy given that these uncertainties include the chance of significant harm to humans and the environment. This dilemma was identified by one interviewee, Virgil, who is from a scientific institution. He said:

> *'The Precautionary Principle cannot offer you guidance as to which path to take. It's like this …You're on a train that's heading towards a broken bridge. There is a bomb attached to the brakes but it's been wired up by a slipshod electrician so it's not certain that if you pull the brake, the bomb would go off. Which course of action does the Precautionary Principle help you take there? So the Precautionary Principle, in my opinion, doesn't help whatsoever with SAI.'* Virgil - from a scientific institution.

For most this double jeopardy was not a consideration, possibly because they framed deployment within an emergency or extreme event scenario, at which point the tolerability of SAI may, despite any risks, overshadow those of the lived experience of intolerable, or increasingly intolerable, climate change affects.

Another important factor explored by interviewees was the lack of trials to date. Nine respondents noted that advocates of SAI, that they were aware of, have as yet not been able to conduct trials, to generate any demonstrations of the scale and effect of side effects. They believed if such studies were available, then a discussion of the precautionary approach would become meaningful and the use of the Principle both more feasible, and likely.

Others suggested the Principle would be required to be implemented if a single EU state were planning deployment given it is embodied in European law. Edward who is from the corporate security industry, for example, said:

'There's at least one European directive on the precaution principle and states would find themselves bound by that if they were challenged by other states.' Edward - the corporate sector.

Following the UK's departure from the EU this may no longer be an issue for the UK, although the extent to which the EU has any binding powers in relation to the Principle is contested, particularly in relation to SAI, as discussed in Chapter 3.

Only one individual, who came from an NGO, did not align with the theoretical expectations, suggesting that deployment, as a response to climate change, would be a natural progression as extreme events frequency increased. They expressed optimism too about the likelihood of SAI delivering cooling with very limited, if any serious harmful side effects.

The interview evidence therefore suggests that the interviewees aligned behind the theoretical expectation that strategic decisions not to act and to implement the Precautionary Principle will be taken, until such time that evidence has accrued that will shed sufficient light on the risks of SAI that they become tolerable.

6.13 Substitutes to achieve similar outcomes with less risk will be developed

The second proposed response is the adoption of alternative actions to deliver similar outcomes. To understand interviewees' responses to this issue it is important first to understand what 'substitute(s)' means. It suggests the use of alternative tools or techniques to resolve the challenge of climate change, without the use of SAI. Possible tools or techniques could be either an alternative geoengineering approach, or other non-geoengineering methods, principally adaptation or mitigation. Geoengineering is generally considered to be neither mitigation nor adaptation, hence its separation into its own class. Adaptation requires that humanity learns to live with climate change and its effects, mitigation that we avoid the problems and geoengineering that we fix the problems.

A third type of substitute to SAI might be the adoption of a typology array of response scenarios. Rather than being tied down to adaptation/mitigation language, such a response would leave space for an ethical appropriateness analysis of what policy options for combatting climate change might look like. Whether this is possible in the context of current climate change policy that is driven by adaptation/mitigation decision options is uncertain. However, the inclusion of geoengineering options as part of a mixed response in the IPCC policy report (ETC, 2013) suggests flexible open approaches to mixed method responses to climate change are still possible.

Alternative non-SAI geoengineering approaches were discussed in Chapter 2 where it was suggested they are likely to be less effective than SAI and whilst GGR is likely to be less controversial than SAI, it is also expected to be less effective. Interviewees' comments reflected these findings with none of them suggesting GGR was a serious contender to substitute SAI given that it is not expected to generate climate cooling. They did however note that it was likely to be far less controversial, not least because it could be contained within national boundaries, avoiding governance issues about the global commons, Ian, a physical scientist for example, said:

> *'I'm very sceptical that even with large-scale GGR that we're gonna get anywhere near the changes we need. So that's no substitute for SRM. GGR has a lot more attraction though as it is often national in its nature so governing it is so much easier. But it can't deliver.'* Ian – a physical scientist.

Possibly in the light of a recent new research programme investment directed at improving GGR capability (NERC, 2016), 14 interviewees and particularly those from the physical science community reflected on GGR as a long-term solution to climate change, but one that would not be viable in sufficient time to replace SAI. Brian from that community, for example said:

> *'Even with this new programme, taking CO_2 out of the atmosphere is just going to take so long. My argument would be: "well we've got to block up the*

sun temporarily, until we get the real solutions". I can imagine people making that argument.' Brian – a physical scientist.

The interview evidence therefore suggests that GGR or other SRM methods are unlikely to be adopted as a substitute in the medium-term (see section 2.3) but that if effective non-SAI geoengineering techniques are developed in the future, they could be used to replace SAI, in effect SAI substituting for those longer-term solutions. This position possibly reflects interviewees' expectations that SAI would be used in response to 'emergency' or significantly more frequent extreme weather events, so SAI would be a necessary stop-gap measure whilst other approaches are developed and taken up.

Pidgeon et al. (2012) have suggested that simply discussing geoengineering may be sufficient to accelerate climate change mitigation by encouraging changes in habits and practices. This view was shared by three of the interviewees and Brian, a physical scientist, had experienced this response saying:

> *'If I'm asked, "What are you working on?" I explain to them, and they say, "Really? You're thinking about doing something that crazy? Wow, climate change must really be a problem. I should worry more about it".'* Brian – a physical scientist.

This effect aside, the people in this sample commonly aligned behind the view that adaptation and mitigation should be pursued as strongly as possible, keeping SAI as a reserve or 'plan B' option. However, half of the participants also suggested that turning to SAI is a serious expectation given the challenges of adaptation/mitigation and progress to date. Ian, a physical scientist captured this feeling, saying:

> *'Adaptation, mitigation? No. What is feasible now is wildly inadequate to what is necessary. So, at the moment it cannot be a serious substitute to SAI.'* Ian – a physical scientist.

The third approach to substitution, the construction of an array of responses received little attention. Although there was some recognition by a few that SAI should be considered alongside other options or as part of a more complex package of measures constructed from an opening up of debate around risk in the mode suggested by Stirling's (2009) heuristic model of responses to problematic knowledge (discussed in Chapter 4). However, there was pessimism among those that discussed this approach not least Virgil, a representative of a scientific institution who said:

> *'You've got three choices: adaptation, suffering and SRM. Three choices, no more. However much Andy Stirling talks about opening up, you won't open it further than those. So suffering is the default.'* Virgil - from a scientific institution.

In summary, should deployment become a serious proposition it is unlikely to be substituted. However, it may be inferred from the interviews that, if SAI were used, it might prompt greater adaptation and mitigation efforts. Also that GGR development investment could produce a SAI substitute if viable. As such, this element of the risk management response seems to align broadly with evidence from the interviews.

6.14 Efforts will be made to improve knowledge

The theoretical expectation is for attempts to be made to increase knowledge levels about SAI such as its risks, effectiveness, the nature of the technology, and its deployment vectors. The majority of interviewees discussed the need for new knowledge and some suggested that this was currently a key issue. James, from a Government Department, for instance, said:

> *'I think that Departments would recognise the absence of knowledge and would put how we might resolve that near the top of the list of things it would like to do.'* James- the government sector.

The fluidity and contested nature of knowledge was also recognised by interviewees who discussed both the importance of scientific evidence, and lay, cultural, policy, and business knowledge being drawn into dialogue about SAI. For example, Joy, a social scientist, talked about scientists being directly involved with other knowledge providers, saying:

> *'The scientific community is less frequently acting as an autonomous agent and I think it is never going to go it alone in this kind of area. They are recognising action does not come from their knowledge claim alone. It comes by coupling knowledges across actors that are capable of action, and they will do this with SAI.'* Joy – a social scientist.

How this coupling might occur was explored by interviewees from NGOs, as well as from the science disciplines. They suggested that deliberative processes might occur alongside the long-term process of science discovery, with discrete evidence interventions contributing to, not leading, global negotiation. This model included small-scale research and testing underpinned by scientists, with interested and affected parties working collaboratively to agree what meaningful tests might look like, how they might be assessed, and what next steps might look like. An un-rushed approach was preferred, with debate in international fora and iteration of full risks and benefits favoured. It was suggested that knowledge would be incrementally gained, with research moving toward small scale 'out-of-doors' research in the long-term. Interviewees said research evidence would then be rigorously reviewed and debated. This type of process was described by Dean, from an NGO, as an epistemic that gravitated to the problem and the construction of solutions, he said:

> *'An epistemic community of SAI could arise. I think that would include policy people in it, that is, the episteme would not only be about solar geochemistry, the episteme would be a composite of belief in climate change, of understandings of atmospheric geochemistry, of what is needed as a solution to a planetary problem, of who has the capability, of who might be most*

affected and so on. So, different forms and modes of expertise with very different interests and motivations, I think, would integrate together into this epistemic community.' Dean - from an NGO.

Within this model, interviewees preferred a 'slow' or un-rushed twin track trajectory of global thinking on climate engineering in which research is conducted with a detailed assessment of direct mechanical risks alongside political deliberations. Research evidence would be published and shared openly across the broadest possible range of interested and affected parties, with researchers seeking to collaborate internationally to seek to assuage suspicion and hostility about their motivations and their findings. Over time knowledge would build. Concurrently, collaborative decision-making bodies would evolve through the political deliberations. These two streams would feed into a hypothetical international forum that would have both the competency and legitimacy to make decisions about deployment of operational intervention. Martin, an NGO member for example described this kind of approach saying:

'Let scientific research proceed under normal controls. Incremental, good governance and transparency, and so on. And, immediately begin international deliberations that take broader political concerns very seriously. Put those front and centre. An early parallel deliberative process framed as consultation among wise, broadly knowledgeable people, something akin to a World Commission, would be sensible.' Martin - from an NGO.

6.15 Where appropriate, measures for containment and reduction will be taken

In this context 'contain and reduce' are interpreted as steps to undermine and question SAI research and development, rather than the use of direct, concrete measures and interventions to stop progress. 16 interviewees clearly recognised that efforts to constrain SAI were in hand with multiple mentions of the ETC and the CBD stands against SAI (ETC, 2010, ETC, 2011, CBD, 2008) that, in the case of the

CBD, did include a direct attempt to constrain geoengineering as a whole. However, interviewees saw these interventions as a natural part of the social appraisal of new technology rather than a genuine attempt to stop SAI or geoengineering in its tracks. Bill, from the corporate sector for example, said:

> *'Well those against it like ETC are really part of the normal debate about new technology. They don't really, I think, want to put a stop to it, end of. It's just they want to be heard, to make noise and make some contribution. There's a difference I think. Of course, there may be genuine attempts to stop it all later on if it gets more tangible.'* Bill - the corporate sector.

Some of the scientists interviewed did believe incumbent interests are seeking to close down the appraisal of SAI (as discussed by Stirling (2008)) even before judgements about the Precautionary Principle are possible. They suggested this had been a strategic move to strangle SAI research, with one using the term 'witch hunt' and arguing that scientific freedom was being challenged. Evidence cited to support this view included comments that journal editors would not publish articles if they included the word 'geoengineering' in the title and the termination of the SPICE fieldwork. George, a physical scientist, said:

> *'I think the issue about freedom to do research is almost a bigger thing than geoengineering. That may be the crunch-point - that you are not going to be allowed to do anything. You get to the point where you're not even allowed to do modelling experiments.'* George – a physical scientist.

This issue was not explored in depth during the fieldwork and is noted here as a point of interest. The literature review has not identified this as a particular issue for SAI, however, it may be an interesting area for further research to establish if the claim has foundation, and, if not, why the beliefs are held.

6.16 Summary of risk management strategy analysis

The evidence from interviews indicates that SAI risk management will broadly follow the Pythia risk management strategies as proposed by the model. The Precautionary Principle will be enacted, substitution explored, knowledge of multiple kinds developed and some forms of containment may be enacted. In the light of this finding, the next stage of the analysis is to explore how deployment decisions may, or may not, be taken, with the theoretical expectation of there being a range of consciousness and confidence-raising measures in play in advance of and during deployment processes.

6.17 Deployment decision processes

The purpose of the risk management strategies is to minimise risk and allow progress through deliberate measures and actions via the three risk bands; intolerable, intermediate and normal (as presented in Figure 4.2). Using the strategies, the model suggests that the risks and risk perceptions would be reconstructed. Resolving, in whole or in part, ignorance, uncertainty, and ambiguity such that SAI may become a normal or acceptable risk.

Renn suggests that, once risk management strategies have played out the final stage of the process, described in the Medusa class, there would be a clear focus on open and discursive public risk debates. This would include steps aimed at: engaging different interested or affected parties, in the form of various publics; and, building understandings of, and confidence in, the technology and the institutions involved in its development, deployment, monitoring and risk management. If such measures were successful, the model suggests acquiescence to deployment would, over time, become tolerable. The respondents' reflections on this are now explored.

There was an expectation among all interviewees bar one that there would be meaningful effort to raise consciousness through public participation and risk communication. This was generally expected to occur in response to an increased sense of urgency to mitigate climate change, rather than as a result of advances in the science and engineering of SAI *per se*. All interviewees suggested scientists, including social scientists, should take the leading role in this activity, and a third suggested this was already underway. Gus, from a government department, for example, said the following about participative dialogue:

> *'Well, it's already underway isn't it? The science community and science policy communities are leading with public dialogues and, well, they funded your PhD and there is that SRM governance group, SPICE, and the Royal Society report. How wide and inclusive it will be, I don't know. But, it's a reasonable start compared to GMO isn't it?'* Gus - the government sector.

The majority mentioned work conducted by social scientists during the SPICE research. However, interviewees' comments suggest it was unlikely that that approach would be an appropriate model when larger, multi-project architectures evolve. They were uncertain whether engagement activities might play out across projects rather than within them, who would be involved and through what process in the longer term. There was commonality among the interviewees' thinking that the participation and engagement process would be a long-term endeavour and that progress would be very slow.

Some characteristics of early stage participatory dialogue were discussed with the suggestion that deliberation and stakeholder debate is likely to be controlled by scientists and research funders. In time, less organised or 'chaotic' engagement was expected to evolve as more is known about the science and the characteristics of the technology. In this 'chaotic' second phase, called '*a bun fight*' by Len, who works in a developing world Government Department, it was suggested dissent would be the default position. Whilst it would be difficult to influence a debate of this nature, which might be taking place in many locations, through multiple media, the interviews indicate that it should be welcomed, and opened up wherever possible.

However, whilst multiplicities of engagements were expected by interviewees, a majority of them recognised that scale participation was not necessarily democratic or inclusive engagement, the preferred option among the sample. Frank, a social scientist, captured this issue saying that:

'Scientists have to recognise they have substantial power in discussions of emerging technologies, they have to find ways to democratise – it must not get locked in too early to particular trajectories. As those with power and influence, we have to do that.' Frank – a social scientist.

Despite the commitment to greater democratisation, few had clear ideas about the discrete methods or processes that might lead to its delivery. Experimental modes of public deliberation, greater participation of civil society, better multidisciplinary collaboration in science, and trying to reframe the debate were all offered as vague approaches to greater inclusion. Others have noted that public dialogue often involves small numbers of homogeneous groups and, that larger groups, constructed with a conscious effort and sampling, can help open up discussions to wider audiences in the absence of other methods of democratisation (Macnaghten, 2010, Stirling, 2009). However, beyond the scope of scientists, including social scientists, six interviewees suggested there was little that could be done by any interested or affected parties to structure or shape debate about SAI if it were to take place in multiple fora and, in particular, the media. Two participants did suggest that new independent, international institutions for participative science, supported by trusted global institutes such as the UN might offer part of the solution to inclusive engagement. But, 'too soon to judge' may currently be the final word in the light of the evidence from these interviews.

6.18 Conclusion

Having explored interviewees' contributions it would appear that SAI fits the prerequisites of the Renn model. The descriptions of SAI risks suggest that it can, given the state of knowledge to date, be reasonably be classified as a Pythia class risk. The interviews showed moderate to strong support for the risk management strategies suggested for the class, although the question of substitution was somewhat problematic, predominantly due to the lack of other technological alternatives, leaving energetic, effective adaptation and mitigation interventions as the only alternate solution. There was strong support for wide-ranging plural engagement during the social appraisal, yet only limited insights as to how that might operate in practice. The following chapter presents the evidence and findings in relation to the governance model.

CHAPTER 7 – ANALYSIS OF FIT TO THE GOVERNANCE FRAMEWORK

7.0 Chapter overview

Chapter 7 presents the evidence and findings in relation to the governance model. Participants identified three likely models, in order of expected likelihood:

- an un-rushed, cautious and inclusive approach;
- unilateral deployment; and,
- a treaty based model.

Respondents suggested that the most favoured un-rushed model would include an exploration of fundamental questions, for example, about the nature of the climate that humanity might choose.

The role that uncertainty is expected to play in the three models is explored and, in the light of this, how dissent might facilitate an opening up and exploration of uncertainty in each model is discussed. The Chemtrailer community, and the interviewees' thoughts about its future role in the technology's governance, are presented. The final section of the chapter, presents whether and how, consent, consensus and concord might feature in the governance of the three models.

7.1 The nature of the governance systems that might evolve

The interviewees did not favour a single governance system for SAI in terms of structures and institutions. Although the UN was discussed by over half of the participants, there was no coherence around their views about the roles that the organisation should engage in. It was however expected to be a useful institution in terms of initialising debate and allowing for open participative dialogue that might be expected to lead to compromise. Views about what might prompt the UN to engage in, or potentially lead, debate were mixed with a third expecting it to attempt to reduce contestation after a single member state, or a small collective of like-minded states, had undertaken some form of SAI deployment beyond research interventions. Of those who viewed the UN as a key actor, they all suggested that it should conduct an un-rushed, gradual governance process inclusive of the widest possible constituency of interested or affected parties.

Ten of the 30 interviewees suggested that the UN might usefully support a process similar to the IPCC climate change discussions, suggesting that such a body, if properly constituted, would have the potential to be accepted by all interested and affected parties as an impartial mandated body which might be responsible for securing resolution of contested issues. Phil, an interviewee from a global institute, for example, said:

> *"It should be the UN General Assembly that should be dealing with this planetary issue. Even the various UN treaty organisations would be too fragmented to effectively deal with the governance challenges of this technology, let alone have it just out there in the world discussed by all and sundry everywhere."* Phil - from a global institution.

As discussed in Chapter 3, a global SAI treaty as a single instrument is considered inappropriate (Armeni and Redgwell, 2015). The majority of interviewees' views aligned with this position, with only one person suggesting that a global governance treaty would be appropriate. Five other participants reflected that existing institutions might be better placed to respond flexibly and quickly to any deployment. Eight of the interviewees noted that the global commons of the atmosphere would create challenging governance issues for SAI but they did not believe they warranted bespoke treaties to regulate them.

There was a strong preference for a more complex but loose set of governance measures and approaches that would develop over time. It was only in the context of some form of climate emergency, discussed by 25 interviewees on 36 occasions, that participants suggested a closed, quick, messy negotiation, with the most powerful states leading the agenda and driving the resolutions. However, having hopefully averted an emergency, those who supported this closed approach suggested that a more inclusive dialogue would follow to bring in a wider range of interested and affected parties to resolve remaining concerns. It was thought that this would help develop a broad consensus about how SAI might be governed in the future and how any harm or loss caused by rapid deployment might be compensated. For example, Humphrey, from a government department said:

> '*Well, you know, if there was an emergency, lots of extreme events in a cluster, say, the big powers, the US, Russia and China together maybe… they might get together and decide to do it amongst themselves. Afterwards… I imagine then they would try and sort it out with everyone else. You know, post hoc governance.'* Humphrey - the government sector.

7.2 Most favoured approaches to SAI governance

The most favoured approached to SAI governance was a gradual, 'slow', or un-rushed process. This did not reflect concerns about climate emergency, but rather it was the approach thought most likely to produce the best outcome. An incremental inclusive approach that progressed in the light of research evidence, but also with feedbacks from processes of dialogue among the fullest range of interested and affected parties possible, including publics who would be unlikely to have any awareness or understanding of SAI. For example, Percy from an NGO said:

> *'I'm optimistic about proceeding sensibly and cautiously and also slowly. I think it's an interesting space in which to make the argument for slowness. You know, messiness and slowness are quite good things to encourage as sort of principles in areas of uncertainty.'* Percy - from an NGO.

The underlying reasoning for such a view was that the final governance of SAI was of less importance than how that is arrived at. Ian, a physical scientist, summed this up saying:

> *'I think what is absolutely critical is the way that we do this, not necessarily just what we do, but how.'* Ian – a physical scientist.

A minority of participants, whilst supporting a gradual approach, were aware of the issues this might cause within the conventional innovation policy community, where it was suggested that speed is seen as an unquestioned good. These respondents were willing to support a 'slower is better' thesis to resist closing down debate and a focus on options and outcomes, prior to resolving uncertainty, ambiguity, and ignorance. This preference aligns with Stirling's (2008) suggestion that opening up and avoiding the early exercise of incumbent power, at the expense of more inclusive development, will contribute to more legitimate governance. The finding also aligns with evidence of long standing concern (Bingham, 2008) that research and innovation are developed faster than the scope of regulatory and ethical oversight. An un-rushed approach might also reduce the capacity for scientists, when viewed through the exercise of their interests (such as those expressed by Pielke (2007) in his characterisation of researcher types - see section 5.18), to accelerate the process unduly, evidence of which, in relation to other technologies, has been identified by Macnaghten and Chilvers (2012).

Key to participants' comments was the importance of keeping open discussion, not only about SAI and technology options, but, more fundamentally, around choices about what type of future, and future climate, humanity may want to live in. Such future-focused ideal governance scenarios were discussed by six interviewees who noted that contemporary discourse focused on agenda such as 'saving the planet', or 'maintaining our climate for our children and grandchildren'. They suggested such interpretations were flawed and missed important *a priori* questions about whether the planet needed saving from climate change rather than, as suggested by Geoffrey, a social scientist, '*saving contemporary liberal capitalism*'.

These participants suggested SAI governance debate offered a unique opportunity to open up these fundamental issues to address questions such as 'What climate do we want' and 'do we have a responsibility to future generations, or should we allow them to determine their own social structures'. By way of example of these views, Freddie, a physical scientist and Zack, from a scientific institution commented:

> *'What about how we choose to live in the future? When we're talking about creating a new environment, it isn't just about environment, it's about the society we want to live in. So then, it's about the climate or planet, good for some, bad for others. I mean we're getting into this whole question about saving the planet. You know, the planet couldn't give a shit. The best SAI outcome for the climate is, to my mind, a completely meaningless issue.'* Freddie – a physical scientist.

> *'Well what kind of a climate do we want?' That's what we should use SAI to ask. All of the politics seems to be focussed on keeping things as they are, safe, which is of course terribly ironic, because the pre industrial climate was shocking for some people, the current climate is shocking for some people and a future, warmer, world will be too. We must now ask, 'what kind of world, social and environmentally, do we want?'* Zack - from a scientific institution.

The 'slow is better' thesis would not only require time, funding, and energy but might also require a willingness to withhold progress in the light of significant scientific advances whilst wider dialogue ran its course. This gave rise to comments about both how science might progress alongside that wider dialogue, and the extent to which that dialogue and SAI governance more broadly would, or should, be open to public debate.

In terms of research, there was a belief that the dialogue should not drive research funding decisions, but that it should be linked to and help inform research direction and pace. A view that correlates with the stage-gate process adopted in the SPICE project. Critically, it was felt by nine interviewees that SAI research should proceed under existing mechanisms of good governance underpinned by robust principles of research integrity, including rigorous peer review, debate in research literatures, and other traditional academic forums. Len, an interviewee from a developing world government body argued:

> *'I take engagement seriously, but you're barking up the wrong tree in demanding that it be assimilated into scientific expertise-based assessment processes. They, I mean the public, can't ask and answer the technical science questions being posed. Let scientific research proceed under something like normal controls, incremental, transparent, and so on.'* Len - the government sector.

Five respondents picked up on the questions of openness and engagement that have been evident in the literature (e.g. (Macnaghten and Szerszynski, 2013)) and discussed whether a democratic process was required. These respondents argued that concerns about a democratic deficit were misplaced, arguing that it is in the nature of democracy to have some deficit, some exclusion of people, and that this would be mirrored in any global processes of SAI governance. One, for example, argued that there had been no democratic process in decisions about the introduction of other globally changing technologies including nuclear weapons and power and the internal combustion engine and that SAI was no different.

Four participants located in Asia and Africa suggested that concern about democratic processes was a western liberal concern about plurality that had limited meaning in many parts of the world, including those that might be expected to experience the impact of both climate change and SAI implementation. On balance, this small subgroup of interviewees suggested that any approach to SAI governance would be a compromise and that whilst they preferred an open participative model, this could not become a global democratic solution.

Having suggested that a democratic model was not possible, an alternative vision of more inclusive open dialogue was explored by those concerned about seeking greater inclusion, if not full democratic representation. These interviewees suggested that those who would be most affected by any decisions to deploy, for example people in developing countries, should lead the governance debate in collaboration with those who have the resources and capacity to conduct research on the technology, who would predominantly be in the West. It was recognised that such a model would be highly challenging to deliver given disparities in power and influence, and three respondents noted that if such approaches to governance were to evolve, important, meaningful shifts in governance behaviours, were necessary albeit unlikely. Dean, who works in an NGO for example said:

> '*New innovations around how we sit together in dialogues are required. They must avoid 'my side/your side', 'I won, you lost' constructions and focus on inclusion of the unusual, the different, the powerless, and affected as well as the powerful, resource-rich world. First off we need way more understanding. But, look, I'm not delusional. This will not happen.'* Dean - from an NGO.

7.3 The free market

It has been suggested that free market mechanisms may be a further driver of SAI governance, if it were to be deployed by commercial interests and, specifically, in what Victor (2009b) has described as a 'Green finger' scenario. In this situation, a rich private actor deploys SAI on his or her own. The allusion here is to the villain in James Bond's Goldfinger suggesting that SAI would be global public bad rather than a global public good. This proposition has been driven, firstly, by the suggestion that the direct cost of SAI is relatively low. Crutzen (2006b), for example, has suggested the costs of a deployment sufficient to counteract the effects of a doubling of carbon dioxide concentrations would be in the order of $25-50 billion per annum. Secondly, in the context of a small number of extremely wealthy individuals increasingly using their resources to pursue a long-term environmental agenda, including, in the case of Richard Branson, offering a monetary award for an effective GGR technology.

Only two interviewees: Robert, from a government department: and, Gemma, a social scientist, thought there was any likelihood of private individuals or indeed corporations deploying SAI at an even micro scale. Robert, for example, commented:

> *'A greenfinger could just decide 'Well I'm going to adjust the way my jet operates and I'll get my millionaire, billionaire friends together and then everywhere we fly we'll spray, we'll be helping. So instead of being a problem, we'll be helping'. But will they do it at a climate level? No. The question is: who could deploy in sufficient intensity to have any effect? Its got to be a collective action, right?'* Robert - the government sector.

The remainder of the 16 participants who discussed the role of the market, agreed it was not a likely or practical proposition. They aligned behind the principle that the deployment and governance process should be a collective action and not be allowed to evolve out of the free market. Nine interviewees did however suggest that power brokers operating within the market could play a lead role in energising efforts toward a future that included SAI. Martin, from an NGO, for example, said:

> *'It needs a big society effort but some of these mega rich futurist types could play a big role. You've got to be really audacious like Elon Musk to say 'Guys, I'm gonna change the world now. Take me a while but I'm gonna change the world.' But I can see them saying that and it pushing the agenda forward.'* Martin - from an NGO.

However, by far the majority of interviewees from across all groups expected a collective process in which market interests might contribute in marginal ways, and some of the interviewees, such as Bill, himself from the corporate sector, were strongly minded that the suggestion of business leading SAI in the future was overstated. Bill said:

> '*I think that is part of the hype in this conversation where people can publish on that and as you know, bad news sells. So, I think that's kind of a silly. I just don't think that there's much merit to it in real life. I also think it would be an international crime if a private syndicate were to go ahead.'* Bill - the corporate sector.

7.4 Uncertainty within SAI Governance

Having explored the nature of the governance systems, the role of uncertainty in that system, in particular in relation to opening up or closing down the governance process, is briefly examined.

The majority of interviewees' comments reflected understandings of uncertainty as a complex, fluid concept with different meanings to different people. Whilst only two respondents explicitly used the term 'closing down' (Frank and Gemma, both social scientists), most interviewees described scenarios where processes of inclusion and opening up of dialogue would be conducted to explore uncertainties.

Participants from the science community tended to focus on the challenges of the scientific method and the relationship between scientific knowledge, facts and uncertainty, and the difference between them and lay perceptions of both the scientific process and in particular how research findings can be contradicting. For example Eli, a physical scientist commented:

> *'Uncertainty is a very technical question that needs the computer modellers and the scientific community to deal with and come out with some answers. Of course, the public and politicians don't understand science. They don't understand it is a process of contestation and change. They just say 'oh scientists, they just can't make up their minds.'* Eli – a physical scientist.

These interviewees saw uncertainty in very technical, specific terms and did not incorporate questions of interpretation and ambiguity into their thinking.

In contrast, interviewees from NGOs, government bodies, the corporate sector and in particular the social scientists, explained uncertainty in more complex terms, as a long-term (see section 2.3) challenge that requires dialogue and exchange to resolve into a condition of acceptability or consensus. Seventeen of the non-scientist interviewees reflected that, in their view, uncertainty was '*never ending*' and complex, particularly in relation to a global agenda such as SAI in which cultures bring a wide range of differing weights or values that are in continual flux between them. For example, countries with vegetarian traditions may put greater emphasis on uncertainty related to possible harm to animals than western traditions, which, it was suggested by an interviewee from an NGO, have very different perspectives on interspecies ethics and the acceptability of uncertainties that may affect them.

Within this 'never-ending' framing such 'insoluble' uncertainty was not seen as problematic. The interviewees suggested that unresolved uncertainties could readily become acceptable or normalised through discourse over time and that this process could be a positive contribution to the construction of consensus. For example, Bill, from the corporate sector said:

> *'I think there's a fundamental level of irreducible uncertainty about all this. There are some things that, no matter how much we put into finding answers, we will not know the answers. Well, that's fine. What is important is how we discuss those and come to a view about what we do. We can just sort of forget them.'* Bill - the corporate sector.

Some argued that this irreducible uncertainty might create an irresistible move toward SAI deployment. Seven respondents discussed this idea, referencing a 'slippery slope' argument where, if uncertainty becomes readily acceptable it allows scientists, engineers and other protagonists to progress SAI with fewer checks and balances. They suggested, once research starts on the technology in earnest, deployment becomes inevitable, reinforced by growing enthusiasm or carelessness amongst those developing SAI alongside diminished feedback from actors less concerned about uncertainties. Whilst the interviewees were not clear about the gradient or direction of this 'slide' they suggested that unresolved, accepted uncertainty could be one of the most powerful drivers of deployment. No interviewee picked up on the alternative 'slippery slope' narrative reported by Stilgoe (2015), that simply raising the topic of SAI was dangerous because it would give the impression that a technical fix to climate change was available and could be turned to in favour of meaningful mitigation.

7.5 Framing dissent

Interviewees' expectations about the extent to which a participative process moving toward consensus, consent and concord might occur were contingent on the nature of the deployment and the extent of dissent. Dissent is the holding or expression of opinions at variance with those commonly or officially held. In the case of SAI this makes dissent a difficult concept to apply. There is no established view about if, how, when or why SAI might, or might not, be deployed. This creates a situation where both those who support taking SAI work forward, and those that do not, can both be considered dissenters. This was noted by Rupert, from an NGO, when he said:

> *Well, who is dissenting? Dissent usually is the negative side, the 'Don't do it' or, you know, 'We're not happy with it', whereas in this case, the proponents of solar radiation management complain that they are the dissenters.'* Rupert - from an NGO.

Without clarification then, using the term dissent is the equivalent of asking the question 'do I think SAI research should continue?' For the purpose of this work, dissent is used as a term to describe interested and affected parties acting on views or opinions that question the scenario under discussion: unilateral, treaty, or collaborative action rather than any presumed position on if and how SAI may move forward.

Dissention can have negative connotations, it can suggest that those dissenting are frustrating change or holding back progress rather than providing a useful reflexive tool. The majority of interviewees in this study, however, described dissent as a positive, useful force creating space for important discourse, problem recognition and resolution. Humphrey, from a government department, summed up participants' perspectives on the role of dissent, saying:

> *'Dissent performs an enormous public service in creating noise and energy around issues that can otherwise get almost completely ignored, serious issues*

about emerging technology governance - extremely valuable.' Humphrey - the government sector.

Interviewees' perspectives on dissent in each of the three main approaches to governance discussed above are explored below in the context of this framing of dissent. However, prior to exploring each governance approach, one group which interviewees expected to remain active whatever governance process might play out is explored.

7.6 'Chemtrailer' dissent

Twenty-one respondents discussed 'Chemtrailers', a community that has been one of the most active dissenting groups in the SAI and wider geoengineering debate. A movement whose dissent has included the use of threats of physical violence and even death toward scientists debating SAI (Grolle, 2013).

The 'Chemtrailers' are a loosely formed group of activists operating from a marginal position where 'chemtrails' and 'geoengineering' are used interchangeably to describe the activists' belief that aircraft contrails are in fact trails of unknown chemicals sprayed into the atmosphere as a large-scale secret government programme of weather and climate modifications, or population control. They argue that there is now virtually no natural weather due to global scale climate engineering and that this is destroying the essentials to sustain life on earth; causing massive animal and plant die-off globally, as well as human illness and death (SNGA, 2017).

Whilst originating from the United States, Chemtrailers are active globally with large groups present in France, Canada, Italy and Germany. A parent website, http://www.geoengineeringwatch.org/ (Geoengineering Watch, 2017), with 28 million separate visits coordinates the campaign and promotes their argument providing a range of material to underpin their thesis. Annual 'Stop Geoengineering' marches are held in 10 countries across the Americas, Europe and the Middle East, documentary films and merchandise are widely available.

Whilst the group may hold views that appear outside the normal range, this does not mean it has a small following. In 2017, the Cooperative Congressional Election Study suggested 10% of the US population were certain that 'the chemtrail conspiracy was completely true' and, a further 20 – 30% thought the theory was 'somewhat true' (Tingley and Wagner, 2017). However, despite this large, active community, this group has widely been dismissed in the academic SAI narrative as being paranoid and not part of the main stream of normal ideas (Cairns, 2014a).

Interviewees in this study took a serious view of Chemtrailers, in particular given the way in which they have participated in the debate, including the threats of violence against academics. However, none of the participants supported taking an inclusive approach toward Chemtrailers, commenting, in line with Cairns suggestions about the approach to this issue, that they were not part of the mainstream. For example Frank, from a government body said:

> *'They're talking about something else. They are, if you like, piggybacking on the SRM debate in order to get their messages heard, but that's a rather different thing from trying to critique or challenge that debate. Really, they are just mad.'* Frank - the government sector.

Five of the interviewees noted they had received multiple communications with Chemtrailers. Their response had been to use a standard reply stating that the technology was only under development, it would be a high-level stratosphere intervention, not something deliverable at low level by commercial jets as suggested by the community, and that there has been no deployment and that there are no plans for deployment. Martin and Zack, from an NGO, and a scientific institute respectively, suggested that those engaged in SAI work had agreed a common response approach with both, saying that they sent a standard reply and shared the correspondence with their own SAI networks.

An alternative perspective, suggested by Cairns, is that those active within the SAI process should openly engage with Chemtrailers. Cairns (2014a) argues that traditional perspectives of how ideas, technology and news, evolve should be broadened to include an increased appreciation of the diverse ways in which citizens conceptualise, construct, and understand ideas, including ideas about environmental change. This is part of a much wider debate about a crisis of truth, driven, in part, by social and other media, and is beyond the scope of this study. However, it does suggest that the Chemtrailer community could remain an influential group of dissenters, proactive in the longer term, and that those engaged in SAI might benefit from at least recognising and including it, whether or not the central beliefs of the group are at odds with all available evidence. Two participants from NGOs indicated this shift toward more inclusive dialogue could be possible saying:

> *'I mean, is it more irrational to think that the climate is being controlled, than to think a few scientists can control the climate? We need to talk, just a bit.'* Martin - from an NGO.

> *'If you get enough people on the planet worked up about all the terrible things that are happening because of the SRM regime, it's going to make it very, very difficult for that SRM programme to continue, even if all of the objections to it are completely nonsensical, unless we really talk with them.'* Percy - from an NGO.

Having explored the Chemtrail issue in terms of its generic approach to SAI, how interviewees suggest dissent may be expressed in each of the discussed deployment approaches is examined.

7.7 Dissent in a unilateral deployment

None of the interviewees believed that processes of consent, consensus and concord would play out prior to a single state or even small group of states deploying unilaterally. But all interviewees who commented on this scenario agreed that this style of deployment would cause dissent.

For example, Freddie, a physical scientist, and Martin, from an NGO, respectively, said:

> *'I think there would be serious dissent afterwards, there are no circumstances in which there wouldn't be serious dissent because it's such a big decision to go it alone.'* Freddie – a physical scientist.

> *'No, of course there will be serious dissent. People will be screaming. The social activists, political activists, the economic activists will be screaming'.* Martin - from an NGO.

Only three individuals expected such dissent to be resolved quickly, and only if the deployment were successful with no ill effects, and there was clear and transparent evidence about future deployment and risk management.

Five interviewees argued that such dissent, whilst potentially disruptive to wider international relations, would be critical if any post deployment influence of the deploying actor were to be possible in the longer term. Three interviewees noted that, given global powers, in particular, China, the United States, Russia, and India were considered the only likely unilateralists, the real extent to which dissent might be sufficient to have meaningful effects on those states was limited. This is particularly the case if those most affected by negative effects were, as has been suggested in SAI literature (Shepherd, 2009), developing world states with little capacity to exert power or influence on the states that were expected to have deployed.

7.8 Dissent during treaty based deployment

With only a single interviewee suggesting that a global governance treaty for SAI would be the most productive approach, and only six suggesting existing institutions are best placed to provide a governance framework, there is limited material from the interviews to inform this framing. Most of the respondents' comments about this model focused on the incapacity of existing structures to satisfy the challenges of SAI's complex reach across a wide range of governance instruments, rather than on how dissent might occur or resolve. However, some tentative insights are offered.

Firstly, interviewees who commented on this approach in any detail all said that there would be dissent, both during the treaty negotiation processes, and beyond, between treaty signatories and others. Geoffrey, a social scientist, for example said:

> *'Even with a global agreement, there would be internal dissent just as we have seen inside the UNFCCC. There will be groups trying to respond constructively and others, opposed to aerosol use, even if state governments were to agree.'* Geoffrey – a social scientist.

The main loci of power through which dissent could be an effective driver of change within the treaty process was expected to be those who were sitting at the treaty table, or advisers to them, and, in particular, scientists. Interviewees expected these 'inside track scientists' to have far greater power than other 'outsiders' including all excluded interested and affected parties and scientists. Those scientists exercising power from within the structural processes were thought likely to be pushing an 'agenda', rather than presenting neutral research evidence. In other words, they were expected to act, in Pielke's terms (2007), as an 'Issue Advocate' rather than, in interviewees' minds, the more appropriate 'Honest Broker'. Such views chimed with sensitivities about scientists' motivations which have been repeatedly flagged in literature urging caution among scientists (ETC, 2010, ETC, 2013, Allenby, 2012),

Beyond the circle of included actors within the formal treaty processes, it was suggested that other interested and affected parties would express dissent through direct campaigning and other media, but also through direct action including being present to express dissent at formal meetings and negotiations. The extent to which such action might exert influence was not clear to respondents.

7.9 Dissent during a loosely framed governance evolution

Interviewees had a broadly common view of how dissent might manifest itself within this governance process. Twenty-three indicated that, whilst dissent would be present, and serious, its expression would be less aggressive than under the other models suggested. Whilst the conversations about possible military intervention or sanctions were applied to a unilateral deployment scenario by some, there was no suggestion at all that such aggressive approaches might appear under this model.

Despite the comments on the nature of the dissent, interviewees were vague about who might be dissenting, beyond very broad categories of NGO's, regions and states, environmental activists, business, scientists, mega cities and new, yet to be established, geoengineering interest groups. Participants were also reluctant to commit to describing detailed pathways of dissent. Only six directly described dissenters' forms of action, with the remainder suggesting that forms of action would be driven by circumstance and the extent to which uncertainty was resolved, or not. The majority of interviewees expressing these views coalesced around the view that the dissenting behaviours would be too 'messy' to understand at this stage in any systematic way.

Of those interviewees that did describe processes of dissent it was commonly considered likely that dissent would be most regularly expressed though actions taken at a distance from those whom they were attempting to influence. Seven respondents indicated that some direct, physically present, action, such as demonstrations would be present in this form of governance process. But demonstrations were expected to be less frequent, although not necessarily less numerous than under the other scenarios, because the duration of dissent was expected to be much longer.

During the interviews, the role of the media in the creation, maintenance, or resolution of dissent was discussed by only one interviewee, Richard, from the corporate sector. He did so when describing how media might play a role in constructing alternative narratives and build increased interest and support for alternative interpretations of SAI progress.

It is interesting that the media was not identified more strongly by the interviewees, whether or not as an amplifier of risk. Not only because the media's role has been recognised in risk literature for some time (Renn et al., 1992, Renn et al., 1995, Petts et al., 2001), but also in the light of the media responses to the SPICE project (Stilgoe, 2015). This is an area where further research would be useful.

Having explored interviewees' contributions in relation to the three deployment scenarios and, how dissent may manifest in each, whether and how consensus, consent and concord might develop is now discussed. Each of the three models is explored, in turn, through the lens of the main governance models discussed above.

7.10 Consent, consensus and concord in generic Chemtrail governance

While Chemtrailers hold beliefs that are unsubstantiated by evidence, it is unlikely that they will reach consent with others engaged with the SAI agenda. Consent requires that Chemtrailers either generate or accept robust evidence or, hand over or take responsibility for the management of uncertainty. It is hard to see this occurring while they hold the position that governments are secretly undertaking geoengineering and wilfully killing their citizens.

Consensus is constituted among actors who have mutual regard, this appears to be absent whilst threats are being exchanged. None of the participants, for example, expressed regard for the chemtrail community, other than Ian, a physical scientist who commended their commitment, whilst not supporting their case, saying:

> '*The fact that they give up their own personal time, that they give a crap about humanity, that they give a crap about people beyond themselves, I think is noble, you know?'* Ian – a physical scientist.

Concord is also difficult to foresee between Chemtrailers and the wider body of SAI engaged actors. The Chemtrail theory sits outside the 'normal' range of SAI discourse and whilst they are continually present and active, it is challenging to see how the positions they hold can be brought into the mainstream governance of SAI.

Of the 21 interviewees who discussed the Chemtrail community, the commonly held view was that, in due course consistent countervailing evidence and consensus among other actors about the evidence, will undermine the chemtrail argument and it will dissipate. Bill, from the corporate sector, summed up his view saying:

> *'Once reputable sources like national academies start to take forward the work in earnest the chemtrail movement basically dies. When there is no evidence for their views nobody's gonna go to their website, they're just gonna be one of those old amusing conspiracy theory things.'* Bill - the corporate sector.

How long this process may take, and the extent to which the chemtrail agenda remains a well-supported and vocal part of the conversation, is uncertain. Considering the extent to which climate change sceptics continue to play an important role in the daily governance debate about climate change, whilst the Chemtrail position is extreme, it may be some time before it changes.

7.11 Consent, consensus and concord in unilateral deployment

Unilateral deployment either at scale or as a research intervention would, evidence from the interviews suggests, be the most likely to create serious dissent, with the nature of that dissent moderated in the light of the power and influence of the deploying state. It is also the only model in which consent, consensus, or concord would not be in train before deployment.

Six of the interviewees, when discussing the implications of unilateral deployment, suggested that it could not only create dissent but also lead to the breakdown of consensus more broadly. Dean, from an NGO, for example talked about this approach to deployment breaking down consensus around humanitarian aid, saying:

> *'If it is deployed, even in a small, symbolic, research flavour, there will be the risk of breakdown in the international consensus. The moment some semblance of unfair global manipulation of the climate is deployed, they say 'OK, I'm no longer responsible for helping.'* Dean - from an NGO.

Downstream, governance of pre-deployed SAI may evolve. This could be in two forms, either, rejection via a global consensus against the deployer, or, given it is the only one of the three authority tools that includes an acceptance of authority, consent to the deployment.

7.12 Consent, consensus and concord in treaty-based deployment

Interviewees said that, among nation states, international treaties are a clear example of concord within which expectations are agreed by self-governing subjects who have, through treaty mechanisms, the ability to be present and active within dialogue about the concord's characteristics and about how issues that affect it are responded too. For non-state interested and affected parties, treaties are closed or distant, meaning that the delegation of authority, other than through state representatives who may have differing views, is impossible and, those not present in the treaty process could not give consent, although they could dissent.

Only one interviewee thought a global SAI treaty was both desirable and possible. However, others did reflect on this model, focusing on how non-signatory, interested, and affected parties would be marginalised in a treaty mechanism, and that this would reduce the opportunity to open up uncertainty and recognise and explore dissent.

7.13 Consent, consensus and concord in complex, loosely framed governance

Interviewees were strongly of the mind that a loosely-framed, open governance model that was as plural and inclusive as possible would be the most suitable model for SAI. It was expected to create dissent, and resolve it. It would open up opportunities to explore uncertainty, better understand ambiguities, and be a positive framework within which science and governments could work. The approach would be time-consuming and slow, and it was only those participants who expected some form of climate emergency to drive deployment who could not envisage this approach developing. The majority of interviewees expected the model to be iterative and repetitive, suggesting that there would be circularity in the consensus process with positions shifting to and fro as dialogue moved forward. Robert, from a government body, for example, said:

> '*Consensus is in a dynamic state and needs constant nurturing. I've got to kind of constantly regain consensus, keep working, juggling, keeping the plates spinning just to keep a position held together. Actually, you know, that's probably more work than to move positions forward.'* Robert - the government sector.

Most respondents expected that the un-rushed model would initially operate to resolve constraints on reaching consensus, rather than to deliver consensus itself. As part of this slower-paced process toward consensus, interviewees expected consent to be gradually given on a broad range of areas of dissent as dialogue resolved them over time. Formalised concord, in the form of a binding treaty or regulations was viewed as less likely in this model, although some suggested formalisation of concord through a treaty could occur, but only as a flagship demonstration of wider consensus and consent. These respondents expected that the guiding principles of any such treaty would rarely, if ever, be tested though its arbitration mechanisms if it were built on foundations of medium-term (see section 2.3), inclusive and plural dialogue.

7.14 How will consensus building commence and who will be involved?

Having identified that participants believed that an open, plural process of consensus building would be most appropriate for SAI governance it is useful to know how this will be delivered, and by whom. Governance activity, in the form preferred, would not occur spontaneously. Respondents had disparate views about what the drivers might be. Six respondents suggested increasing the economic, social and political effects of climate change would act as a 'wake-up call' to encourage disparate groups to seek to resolve conflicting positions about SAI. These respondents, such as Bill from the corporate sector and Joy, a social scientist, noted that they were thinking of gradual changes rather than emergency scenarios:

> '*I think it becomes salient when the barbarians are at the gate and, therefore, it's going to take some wake-up calls. Not in the form of serious events. Stern putting out another paper on how bad it's gonna be economically and how little the costs of climate engineering are, comparatively to these other things. That kinda thing.*' Bill - the corporate sector.

> '*I suppose we will engage when there is … something that we can all stand behind and unite, and get over our secular ways of dealing with things. I suppose mild adversity tends to bring us together, or certain groups together at least.*' Joy – a social scientist.

Other respondents argued that the way in which the engaged parties thought about their relationships and objectives would need to change before suitable conditions for progress were arrived at, suggesting a shift away from bifurcated views about 'winning' and 'loosing'. Martin, an NGO member expressed this most clearly, saying:

> '*We must have an innovation in how we have a conversation. I think that too much of what happens … it's all designed with a premise of my side and your side, with mechanisms that amplify the avoidance of losing face… the one who lost, the one who gave up. That has to be consigned to history before we can really have constructive governance dialogue about planetary agenda.*' Martin - from an NGO.

Twenty-three respondents said outreach of robust trusted, impartial, independent and international science was critical to prompting dialogue. Underlying this idea was a notion that science had increasingly gained standing amongst those whom respondents felt would be engaged in debates through the work of the IPCC and on climate change more generally, Gus, an interviewee from a government department noted:

> *'I think we'll find that there's greater acceptance of the science because the science community has broadly been very good at making sure that the evidence is there and been very self-questioning. I think there'll be a bit more listening and responding to science in relation to geoengineering when they talk about it.'* Gus - the government sector.

If science is indeed to be part of the conditions that facilitate dialogue, scientists and their work must be visible to and within the governance community. Nine interviewees suggested this would require applied research directed toward delivering some form of impact, rather than basic or blue skies research. Peter, from a scientific institution for example, said:

> *'A scientist who has been given a research grant to deliver certain things and impact is going to have the conversation about governance on the side; they will do it if the incentive structure is there.'* Peter - from a scientific institution.

However, there was also some scepticism about whether SAI-related science would be successful at informing dialogue because of perceived failures in the science communities' efforts to communicate climate change evidence effectively. This frustrated some respondents who felt people chose not to accept climate change science, whilst they were willing to accept other, more convenient products of science. Martin and Joy, physical and social scientists respectively, said:

> *'We find it exasperating that people wilfully choose to just deny climate change while they're talking on their cell phones, the product of science, while they're eating the food that has been delivered to their homes which is the product of this vast system made possible by science. They are basically saying:*

'No but in this case all of that science doesn't apply.' Martin – a physical scientist.

'The scientists got it right on all these other things… my TV, my printer, my computer, the medical science that saved my baby when I was going through that difficult childbirth? That's all good. But the science of climate? Nah, they don't know what they're talking about.' Joy – a social scientist.

This suggested separation between the perceived legitimacy of climate science and the technology derived from it was seen to be a functional impediment within SAI governance debates. Those who discussed this, argued that scientists, seeking to engage in SAI dialogue outside of their own community, should do so alongside intermediary 'climate technologists' who would jointly present their contributions about SAI. For this to happen respondents believed incentives to encourage scientists and 'climate technologists' to work in conjunction were essential. However, they believed current incentives for the two communities were not on a converging pathway, which would limit the capacity of scientists to move the SAI governance debate forward. Peter, a representative of a scientific institution, expressed this view saying:

'To have an SAI governance conversation, we need a third set of actors who understand what's going on in technology, who understand what the climate scientists are telling you, and who understand the limitations of climate negotiations. To breach these worlds we need an incentive to make it happen.' Peter - from a scientific institution.

Interviewees suggested that a wide range of actors would be involved in the dialogue, as shown in Table 7.1. Four of the interviewees said that scientists were already engaging in efforts to engage others in plural debate through, for example, public engagement activities and the SRMGI.

Table 7.1 Actors involved in participative dialogue

ACTOR	NUMBER OF RESPONDENTS IDENTIFYING THE ACTOR
Scientists	26
NGOs	24
International fora, including IMO, OECD, CBD, IPCC	23
United Nations	23
Citizens and citizen groups	21
Environmental pressure groups	19
Self-identified collections of nation states	11
Security agencies	9
Global finance and banking	7
Competent bureaucracies	6
Cities and regional government bodies	6

Scientists were the most frequently discussed non-institutional group expected to be engaged. NGO's and a range of international fora, alongside the UN, were also frequently identified. Perhaps notable by their absence are politicians and heads of state.

7.15 Some characteristics of un-rushed governance processes

A key underpinning rationale of respondents favouring the un-rushed approach was that it would offer the best opportunity for the co-production of a sound governance process. This would authentically embody diverse values, meanings and perspectives on the risks and their management, and, would facilitate greater democracy, equity, equality, and justice than a more closed approach.

The interviews did not explore in detail what would characterise successful un-rushed governance processes. However, a small number of participants did touch on this in passing.

The ideal approach envisaged by interviewees would be at odds with traditional types of structured engagement, with intensely participatory, interactive modalities most highly favoured. These would be time-consuming, expensive and might, *prima facie*, show little benefit in the short-term (see section 2.3). It was thought, if significant barriers were to be dissolved, better engagement structures that allowed the joint exploration of new solutions were essential. Dean, from an NGO, suggested interactions would be best conducted through the use of humour and playfulness using original forms of interaction such as gaming and role-play. This question of what would constitute a good process was not a focus for the research questions but does warrant further investigation, not least given the timeframe and scales over which the process might need work.

7.16 Summary

This analysis chapter has explored, in detail, the governance findings of the study, testing the theoretical framework against the evidence of the interviews. This showed little support for a treaty-based governance model among the participants, who favoured a gradual process, which would be incremental and inclusive. Interviewees suggested this would progress, in the light of research evidence and with feedbacks from processes of dialogue, with the fullest range of interested and affected parties involved. The role of the market was not expected to be central.

Uncertainty and ambiguity were recognised as key issues which, rather than being problematic, were thought to be able to help drive resolution, if the favoured model of open, un-rushed governance were followed. The Chemtrailer discussion raised questions for the science community, in particular about how they presented and made knowledge available, with a view to exploring uncertainty in the context of competing sources of information, in particular, from social media.

Within the preferred governance mode, with embedded conversations and exchange among a broad range of interested and affected parties, interviewees gave strong support for consensus building. Key to this would be the science community's role in developing conversations, possibly through informed intermediaries.

In Chapter 8, the findings presented in the two previous chapters are summarised and the two key research questions are answered.

CHAPTER 8 – SUMMARY OF FINDINGS

8.0 Chapter overview

This chapter summarises the findings of the 30 senior stakeholder interviews (as presented in Chapters 6 and 7). First, it answers the two key research questions. It then proceeds to review the extent to which the expectations of the study's theorised models of risk management and governance were met, including the fit with the Renn model of risk and risk management (introduced in Chapter 4, section 4.7), and whether governance of SAI may develop through the processes of consent, consensus, and concord (as identified in Chapter 4, section 4.2).

8.1 The core research questions

To recap, the two core research questions addressed by this thesis are:

- how might deployment risks be incorporated into SAI governance; and,
- might SAI governance be plural?

How might deployment risks be incorporated into SAI governance?

In the light of the evidenced reviewed in Chapter 6, based on interviews with a range of stakeholders, there is a strong case to suggest that deployment risks will play a fundamental role in governance processes, and will drive how conversations about SAI move forward. Deployment risks are expected to create divergent views and dissent which, in turn, will create opportunities for inclusive governance debate. The complexities and uncertainties of SAI's risk will slow the governance process. But, because a less-rushed approach is seen as a very positive trait, it will enhance the process, meaning that SAI governance will potentially be more inclusive, open and comprehensive.

Might SAI Governance be plural?

The study suggests that SAI governance will be highly inclusive and plural, allowing a broad church of interested and affected parties to contribute and exercise power within the governance process. Unilateral deployment by a nation state or an independent 'Greenfinger' would be the least plural of all options, but it is also by far the most unlikely. However, plurality will be constrained to the extent that it will not be democratic in the strictest sense. There will not, for example, be a formalised process to encourage inclusivity, nor majority representation. The complex, plural process described creates significant, pragmatic questions, about process. In particular, questions about timescales and geographical and cultural reach, who might drive or participate in them, and to what end. Whether a plural governance framework as described could, or even should construct any form of schedule or deliverable targets for SAI, or indeed in any other early stage social appraisal, remains unaddressed in this study. Further, the study does not address how a trans-global or trans-state process might operate, nor is there any experience of attempting to do this to draw from.

8.2 Risk importance and characterisation

The interviews clearly show that the risks associated with SAI are viewed as a critically important and difficult governance challenge, not least because risk identification is incomplete, and the technology is yet to be fully developed. Uncertainty remains around those risks that have been identified, both in terms of their scale and likelihood and, ambiguity. For example, the sort of climate that humanity would choose, requires resolution if progress toward reducing uncertainty is to be gained. The evidence also suggests that interested and affected parties would reject any governance interventions that sought to use quantitative cost-benefit solutions to risk management and, that they would favour the inclusion of a full range of knowledge types within any risk appraisal, or governance activity.

8.3 Fit with the Renn model

SAI characteristics were explored with interviewees to establish the fit with Renn's six risk classes (summarised in Table 4.1). Given that the interviewees characterised SAI as an uncertain risk, where the probability of occurrence, the extent of damage, the allocation and the way in which the damage manifests itself is unknown due to high complexity, the technology clearly fitted the Pythia risk class. The analysis then examined how SAI risks might be managed, and, whether the findings from the interviewees did, or did, not coincide with the model's five risk strategies, which are to:

- take strategic decisions not to act and to implement the Precautionary Principle;
- seek to develop substitutes to achieve cooling, or, effective adaptation;
- improve knowledge;
- take measures for containment or reduction; and,
- develop emergency management plans and tools.

The evidence from the study suggests SAI risk management will broadly follow these five strategies, as shown in Table 8.1. Only one of the 30 participants rejected any use of the Precautionary Principle. The remaining contributors all expected that the Principle would only be enacted, constraining deployment whilst further evidence is gathered and research conducted. If sufficient light were shed on the risks of SAI, and uncertainty reduced, interviewees expected increased tolerability, and that the Principle would no longer drive SAI governance.

None of the interviewees expected that any substitutes, including GGR geoengineering, could deliver a suitable alternative to the cooling efficiency of SAI within anything less than a multiple-decadal timescale. However, it was suggested that, if effective GGR were developed in the next fifty or more years, it would likely then be used as a SAI substitute, if it had been deployed. Respondents said adaptation and mitigation should be pursued as strongly as possible, and that both

Table 8.1 Summary of alignment with Renn's risk model

MODEL EXPECTATIONS	ALIGNMENT	EXAMPLES OF EXPECTATIONS
Risks characterised in variable ways	YES	A wide range of risk characterisations driven by, for example, political, scientific, social, and cultural perspectives.
An intolerable risk can become tolerable	YES	Supported by every respondent
Interviewees' characterisations of risk aligned with Pythia class	YES	A strong alignment, e.g. concerns expressed about probability of occurrence, extent of damage, and its manifestation.
ALIGNMENT TO RISK MANAGEMENT STRATEGIES		
Enactment of Precautionary Principle	YES	But, with on-going research and an option to discuss deployment in time.
Seek to develop substitutes	YES	With little or no expectation of GGR, or adaptation and mitigation, being successful at the required scale.
Improve knowledge	YES	Strong support for research and wider debate and deliberation to enhance knowledge about perspectives on SAI, climate change, and the knowledge creation process.
Take containment measures	YES	Some suggest that this is in play through the exercise of incumbent interests, e.g. ETC, CBD and the science policy community
Develop emergency management plans	PROBABLE	Thought not to be required at this stage. Expected, as knowledge about the technology and effects improved.

were preferable substitutes to SAI. However, over half of the sample expected both adaptation and mitigation to fail to meet current adaptation and mitigation targets, including the Paris Agreement 2050 targets, and took the view, that, if significant uncertainties could be resolved, SAI deployment would be preferable to solely pursuing adaptation and mitigation with little chance of meaningful success in the short-term (up to five years, as identified in Table 2.3).

At this stage in the technology's development it was felt there was no realistic need to develop emergency management plans. There was strong support for improvements in knowledge about SAI both in terms of basic research and in engineering knowledge. This, it was hoped, would be conducted alongside un-rushed dialogue and engagement activities, with a comprehensive plural range of interested and affected parties.

Rather than contain SAI development through deliberate measures, the evidence suggests that social appraisal should be allowed to take its course, and that this would, if appropriate, contain deployment. Some scientists in the study took the view that there were incumbent interests at work trying to contain, or stop SIA development.

In terms of decisions to deploy, the study suggests that there will be meaningful efforts to move toward developing the technology to a position where deployment becomes an option. Critically, however, it indicates that there is a significant need for meaningful efforts to raise consciousness through wide participation in risk debates, and that this must include deep deliberation across multiple interested and affected parties with efforts to be as 'democratic' as possible. All of the interviewees agreed that scientists should play a key role in this, otherwise the findings lacked clarity about who else should be involved, beyond broad categories of actors, and in particular, what kinds of discrete methods or processes would best be adopted to deliver appropriate, comprehensive and valuable outcomes.

In conclusion, the study suggests SAI fits the Renn model, and it is broadly an appropriate tool for interested and affected parties to use to frame how SAI risk management and governance may move forward.

8.4 Match with the theorised model of governance

The interviews reveal that nation states are expected to play an important role in SAI governance. However, interviewees did not expect them to operate with power in a hierarchical fashion, driving forward deployment without regard for wider governance actors. Rather, the participants' views aligned with the theoretical perspective that suggests that a multiple plurality of actors would be present in SAI governance. This confirmed the theoretical expectation that authority within SAI governance would function as an achieved condition, as an outcome of complex variable practice across multiple interested and affected parties.

Further, the theoretical framework suggested that if open, plural approaches to governance were under consideration, stylised upstream governance would be rejected. The evidence presented here suggests that such open processes are being taken forward by the science and engineering communities within the context of their research, and that they may continue beyond any tangible commitments or institutional, economic and infrastructural attachments being made to any particular SIA pathway.

8.5 Modes of governance

In terms of governance, there was no support among the interviewees for any form of global SAI, or wider geoengineering treaty, and all the views suggest a more complex patchwork of measures, both formal and informal would be appropriate. Such an approach was expected to evolve from a gradual process, which would be incremental and inclusive, progressing in the light of research evidence, and with feedback from processes of dialogue with the fullest range of interested and affected parties, including a wide range of publics. Included in this, some suggested there should be much deeper conversations about the type of world, including, but not exclusively, the type of climate that we want to live in. However, this raises questions about whether such a model will deliver optimal outcomes or if it might lead to unrelated or uncoordinated deployment decisions.

The role of the market, corporations or so-called 'Greenfinger' like individuals was not expected to be central to the governance of SAI. This reflects the current lack of any clear market opportunity in SAI. There is, for example, no market price for tonnes of aerosol distributed or cooling delivered. Nor is there a model available to underwrite any insurance risk that might arise for a business, which caused global-scale harm or loss (Smith, 2014). The vast majority suggested that their role would only be as one of the many parties present in the proposed exchange and dialogue process. However, this group is recognised as having the potential to play a leading role in energising research and governance participation.

The role of ambiguity within the SAI governance modes identified by the respondents was discussed in section 7.4. This suggested that the role of culture and economic and social realities would be key in creating a variety of ambiguities within uncertainty. The issue was particularly recognised by participants from outside Europe and the United States. These complex uncertainties were described as 'insoluble uncertainty', but were not seen as deeply problematic. Interviews suggested unresolved uncertainties could be useful in promoting discourse, and that they could be normalised within consensus. Equally, dissent driven by normative and interpretive ambiguities about the technology's risks was perceived as having the capacity to be a positive force with the potential to create opportunities and space for problem recognition and resolution.

8.6 The role of consensus, consent and concord

The findings regarding whether the identified SAI governance modes would play out through consensus, consent and concord are summarised in Table 8.2.

Table 8.2 Summary of alignment of the consensus, consent and consensus framing

EXPECTED GOVERNANCE MODE	MODE ALIGNMENT	COMMENTS
LOOSELY FRAMED GOVERNANCE (the most favoured model)		
Consensus	YES	A complex plural process that would be circulatory and on-going.
Consent	YES	Gradually achieved with dissent as a key, positive, driver.
Concord	IN PART	Only in the form of informal agreements, or possibly treaties. as exemplars of where consensus and concord are reached.
UNILATERAL DEPLOYMENT		
Consensus	NO	No expectation of any possibility.
Consent	NO	No expectation of any possibility.
Concord	NO	No expectation of any possibility
TREATY BASED DEPLOYMENT		
Consensus	IN PART	No expectation of any possibility, other than among signatories.
Consent	IN PART	No expectation of any possibility, other than among signatories.
Concord	IN PART	No expectation of any possibility, other than among signatories.

Were SAI to be deployed by a single state, the evidence suggests there would be no consensus, consent or concord, and that there would be significant dissent. The extent of the dissent would reflect the power and influence of the state, or small group of states, that had undertaken the deployment. The dissent would remain a tangible issue for a very considerable period of time post-deployment.

Participants agreed that a treaty approach to SAI would be one of concord among the signatories, but this approach was not supported because it would close down effective governance participation for non-signatories. There could, however, be consensual support for any treaties, but also contestation and dissent.

Within the preferred loosely framed, open governance mode with embedded iterative and repetitive processes there was strong support for processes of consensus building. For this to develop around SAI a prompt, or 'wake-up call', was thought to be required. This might take the form of an acceleration of climate related extreme or unusual events, or, more challenging, the development of new ways of thinking about relationships more broadly with stronger commitments to cooperative mutually beneficial outcomes.

Science was identified as having a particular responsibility to develop conversations with a view to allowing dissent into the process and playing a sensitive role in moving toward consensus. Within these processes, the findings suggest that scientists must be conscious of how others perceive science's claims to knowledge and legitimacy. It also suggests they should consider working with intermediaries to help bridge gaps between the science community and other interested and affected parties.

8.7 Conclusion

The research broadly confirms the expectations of the theoretical framework and provides robust answers to the thesis' core questions. The Renn (2008) model proved appropriate for use with SAI and, given the current state of knowledge about the technology's risks, it aligns well with the Pythia risk class. In addition, the interviews showed moderate to strong support for the risk management strategies suggested for the class.

In terms of models of governance, the participants showed little support for unilateral action or treaty based governance, in favour of gradual, incremental and inclusive processes. Uncertainty, in all its forms, was recognised as a key issue and informed respondents favoured choice of an un-rushed governance process. The Chemtrailer discussion raised questions about how better to present and make knowledge available. Interviewees gave very strong support for consensus building within the preferred governance mode, with embedded conversations and exchange among a broad range of interested and affected parties.

Chapter 9 discusses the strengths and weaknesses of the study and some of the insights arising from it.

CHAPTER 9 – DISCUSSION

9.0 Chapter overview

This chapter explores the extent to which the research was capable of addressing the core questions. It highlights the strengths and weaknesses of the theoretical framework and research method, and explores some wider insights for SAI appraisal identified during the interviews. It reviews the extent to which the theoretical framework enables an understanding of the governance of risks associated with SAI, and the extent to which this can be applied more generally. It demonstrates that the Renn (2008) model worked well as a typology, and a descriptive tool, with which to understand risk management. It then proceeds to review the extent to which Bulkeley's (2012) consensus, consent and concord model helped explore how dissent will function within governance, and how useful it was to address how authority functions. Some thoughts are then given on the extent to which consensus, consent and concord usefully operated as a typology.

The review of the research method shows that it delivered the required insights in the light of the methodological criteria presented in Chapter 5 (section 5.2). The method is reviewed and a number of suggestions about how it might be improved to enhance future SAI research are offered. The chapter concludes with an exploration of the wider contributions to SAI scholarship, suggesting a number of insights to inform current SAI debates.

9.1 The value of the theoretical framework

The theoretical framework for the study was constructed with a view to providing a way to explore the research questions identified by the thesis. Rather than 'importing' a ready-made theorising of SAI governance, it drew on a risk management theory (Renn, 2008) and climate change governance literatures (Bulkeley, 2012, Bulkeley and Newell, 2010), providing a descriptive tool which helped provide models for how and why people thought about the issues. Renn's (2008) theory provided valuable explanatory power – and the governance model also provided new insights on how governance of SAI risks might be understood. The theoretical framework helped explain how interviewees' various perspectives came about the way they did, and the connection between risk characterisation and management with governance.

Risk management was explored through Renn's (2008) model not only because it includes recognition of, and accounts for, uncertainty and ambiguity through holistic concepts that transcend probability and loss, but it also allows for a broad range of risk characteristics to be included. These were key challenges identified in the technology appraisal literature (Stirling, 2008, Stirling, 2009). On reflection, the framing, and the interview question construction, did, in the way expected, allow for an opening up of understandings of, and conversation about, risk.

Central to the risk model (as outlined in Chapter 4) is an understanding that risk is characterised, interpreted and acted on differently by differing groups, actors and publics, and that these variations can have significant effects on risk governance. This was very strongly reflected in the interviewees' contributions, which also reinforced the choice of theory employed to examine the risk agenda.

A further key expectation of the framing was that participants would agree that an intolerable risk could become tolerable. Given that all 30 participants agreed with this position this further supported the model selection. Had this not been the case, the risk management framing would not have proved suitable as a way of exploring governance, as defined as a complex process drawing on a plurality of actors. This is because the only risk management outcome expressed in Renn's (2008) model to such a circumstance would be joint strategic decisions not to act, other than to enact the Precautionary Principle through international law.

In terms of the governance framing, the selection of Chhotray and Stoker's (2009) interpretation of governance as a complex process drawing on a plurality of actors was appropriate. This was reflected in the way in which participants identified a broad range of interested and affected parties whom they expected to be engaged in SAI governance. Adopting consensus, consent and concord as a model (Bulkeley, 2012) through which to establish how the technology's governance might play out provided a structure which helped the analysis, particularly in relation to understanding how dissent, which was identified as an important driver of SAI debate, would likely be incorporated into future governance. The approach also provided a useful way to discern how the giving and taking of authority would function. The three categories could not be described as a successful typology of SAI risk governance. This, though, was not their function within the theorising, which had been to operate as a descriptor of processes, not an analytical tool against which success, or failure, would be tested.

9.2 The senior stakeholder interview method

The method used in the study was designed to test if SAI would fit two models of risk management and governance. It aimed to illuminate how interested and affected parties assess the risks of SAI and, how they might be incorporated into future governance of the technology. A number of criteria were established (in Chapter 5) to inform selection of the method to ensure it was capable of testing the validity of the theoretical framework, and answering the research questions. The criteria described were that the interviews would:

- allow for normative judgements concerning evaluations of particular governance scenarios, such that participants could validate outcomes themselves;
- incorporate multiple views in a symmetrical fashion without unduly privileging any one perspective;
- elicit rich contextual insights; and,
- be resource efficient, convenient and accessible to participants.

On reflection, the number and richness of the normative statements and positions offered by the participants throughout the interviews suggest this objective was met. The capacity for the interviewees to be reflexive and to self-validate their contributions during the interview process is less easy to establish. Interviewees certainly frequently re-considered their views and positions during the interview process, and many times an interviewee would change their position or thinking about an issue in the light of the conversation. In particular, for example, in relation to thinking about when and what a 'climate emergency might be'. Therefore, the interview approach did not, at least, frustrate respondent's capacity to self-validate their contributions. Had time and financial resources been available, this could have been tested through follow up interviews or inviting the participants to reflect and comment on the transcripts of their interviews.

It is important to note that there were few areas where a large majority of the interviewees - over 25 of the 30 participants - aligned behind a single common position. Generally, whilst majority views were expressed, they were often nuanced with subtle differences. Neither were there any discernible clusters of thinking among the actor groups selected. This complexity was expected and was one of the reasons why any consideration of a quantitative method was dropped early in the project's development. Through careful attention to ensuring that the full range of perspectives aired by all participants were considered during the analysis, and reflected in the presentation of findings, no one perspective was unduly privileged.

A key strength of the sampling approach was the decision to include interviewees from around the world. Some of the richest contextual insights, with the most illuminating thinking, came from participants from Asia, South America and Australasia. Whilst there has been SAI debate in those regions, those working and thinking in the field had probably not been as strongly influenced by some of the more prominent SAI conversations in the West, such as the SPICE project and the Royal Society report.

The final criteria, to be resource efficient, convenient and accessible to participants, was fulfilled. Having the option to undertake interviews on a face-to-face basis, by telephone or Skype meant there was some flexibility for interviewees, allowing them to participate at times and from locations best suited to themselves. The ESRC's Research Training Support Grant funding was helpful in supporting fieldwork costs including travel and telephone call charges.

Despite these successes, the design of the study could have been improved. A larger sample size, given sufficient time and other resources, might have provided an even richer evidence base from which to draw. Nevertheless, whilst, there were few topics on which all interviewees completely agreed, there were very few areas where there were any strongly outlying sets of opinion, suggesting that whilst a larger sample may have revealed more depth. It would not have led to different findings.

The high refusal rate does not suggest the chosen interview method was at fault. SAI is a novel technology and a challenging topic. It is not one about which many institutions, particularly in the private sector, have developed thinking or policy positions, and some of those who declined an interview request reflected or cited these issues. However, as was noted, during the pilot phase there was some hesitancy among certain individuals about participating in the study, because of concerns about my independence from research funders or other science policy institutes due to my previous role. Retrospectively, it might have been useful if the study had included an interview decline follow-up, to explore the reasons why.

In terms of the sample quality, all of the senior stakeholder interviewees had been engaged, to some degree, in SAI debates. This may be why they agreed to participate in the study. This suggests that future research could usefully seek to secure participation from less expert or non-expert respondents, raising methodological questions about how to secure participation.

Most of the interviewees clearly demonstrated a good grasp of the nature, likely risks and governance issues raised by the technology and the quality of the evidence can be said to be high, being based on a sound knowledge base. It would, however, have been welcome to have included more women in the sample. Significant efforts were made to include women, including using recommendations and trying to snowball interest in the study. However, the difficulties experienced do reflect Buck's (2013) wider experience of SAI as a gendered topic.

The Chemtrailer community, a dispersed group of activists who believe SAI has been used for many years by governments who wish to control the climate and/or kill its citizens, was not included in the study. This decision was taken because their views are considered to be beyond what are generally considered the normal understandings of current evidence about the atmosphere, climate and technology, and also because of the threatening behaviour exhibited by a small minority of the group. However, as discussed in section 7.6, this community does raise important questions for science about the meaning and value of knowledge and the credibility of evidence. It is possible that their inclusion could have provided for an even richer set of findings. It would, however, have been unlikely that their inclusion would have led to different findings and, as an 'anti-group', they might have refused to engage, preferring to remain outside the normal processes of research to retain power. Further, as suggested by Stevenson and Dryzek (2012), any inclusion of an outsider group in the process would have required that the representatives were willing to engage with the research not as 'enemies' to be defeated, but as respected adversaries, a proposition that Cairns (2014a) indicates may be optimistic.

9.3 Contributions to wider SAI debates

In addition to addressing the central objectives of the research, the study has provided some wider insights that can inform SAI appraisal. These include:

- the extent to which the technology is unique;
- whether there will be a democratic deficit in SAI governance;
- that emergency narratives have retained salience amongst interested and affected parties (despite expectations in SAI literature suggesting this is not the case);

- how SAI could inform some fundamental questions about governance of the Anthropocene; and,
- the wider political landscape.

These are discussed below.

9.4 Questioning the distinctiveness of SAI

Many claims have been made that SAI is, in governance terms, distinct from other technologies and that it requires special consideration and novel treatment (Kreuter, 2015, Morton, 2015). This is an important issue, because it raises questions about whether the governance *status quo* will remain viable in a geoengineered world, and whether current risk management and governance theories are fit for purpose. For example, it is suggested (Morton, 2015) that, historically, environmental governance has predominantly been construed, constructed and exercised as a tool of enclosure, of claiming or protecting property, but SAI, uniquely, requires that governance address how the well-being of a key global environmental system is secured, to protect the long-term viability of the planet for human flourishing. The extent to which SAI is distinct, and whether that creates a requirement for novel governance models, are informed by the study findings.

Whilst technology has progressively changed the chemistry of the atmosphere and oceans, the hydrological cycle and the albedo of the land surface (Goudie, 2013), the claim for SAI is made because of the 'intentionality' associated with its use. For the first time SAI would allow humans to make a conscious choice to change the planetary system directly and knowingly. Respondents recognised this proposition, but also discussed other global scale technologies:

- agriculture;
- the Haber Process; and,
- nuclear weapons.

However, none of these is completely comparable to SAI.

Thirty-eight percent of the Earth's total land mass is used for agricultural food production (UNFAO, 2003). This effects surface albedo, changes water cycles, and is disrupting ecosystems. The use of pesticides is having significant effects on insect populations, for example, it is suggested that the total flying insect biomass in Germany has decreased by more than 75 percent over 27 years (Hallmann et al., 2017). Agriculture is, however, unlike SAI. It is a complex system, underpinned by an array of different technologies conducted at multiple scales. Importantly, the intention of agriculture is to produce food, not environmental change.

The Haber Process, which fixes nitrogen for fertilizer, is credited with feeding a third of the world's population and half the nitrogen in our bodies is present because of the Process. It has been credited as the biggest driver of population growth in human history (Smil, 1999). The impact of the Process on the nitrogen cycle is proportionately greater than the effect of all anthropogenic fossil fuel consumption on atmospheric carbon levels, and humanity converts more nitrogen into fixed forms than all natural systems combined (Erisman et al., 2008). Rockstrom et al. (2009) have suggested that anthropogenic nitrogen cycle disruption is three times over the safe operating limits for Earth system well-being.

The Process, then, has global scale effects. However, it is diffused and deeply embedded. The levels of nitrogen result not from a single effort to engineer, but from the combined impact of many separate organisations producing nitrogen at scale for well over one hundred years. In a similar vein, the release of anthropogenic greenhouse gases is currently undertaken in the knowledge of their effect on the climate. However, the intentional changing of the nitrogen cycles through the Haber Bosh process and the heating of the planet through the release of GHG are by-products of actions undertaken for other purposes. For example, increasing agricultural productivity (and the more efficient manufacture of nitrate-based explosives), and the generation of heat and power respectively. SAI on the other hand would be undertaken with the direct intent of affecting the climate, a direct intent to geoengineer, suggesting SAI is unlike these interventions (Curvelo, 2014).

During the study 11 interviewees suggested that nuclear weapons were an analogous technology and that their governance could provide some insights for SAI governance. Eight participants noted that the use of multiple nuclear weapons in a strike designed to defeat another nuclear state would not only lead to direct casualties and destruction, but that within a very short time-frame the planet would enter a nuclear winter, an extreme version of SRM. It is not to go un-noted that some SAI climate effect modelling draws from the science that has informed evidence about the scale, impact and duration of a nuclear winter (Keith, 2013).

Whilst nuclear weapons are an exemplar of a large scale, high impact technology that would be used intentionally and have global effect, interviewees highlighted two clear distinctions with SAI. The weapons have near instant effect once deployed, whereas the effects of SAI would ramp up slowly, and could be ramped back down again slowly after initial deployment, meaning that there would be considerably more time available for governance dialogue about SAI deployment and on-going governance than nuclear weapons. Secondly, the purpose of nuclear weapons is to destroy people and the environment, whilst the purpose of SAI deployment would be to preserve life and protect at least some elements of the environment and ecosystems that would otherwise be damaged by unabated climate change.

The study suggests, then, that SAI, through its intention to change the Earth system, is unique, and that it creates novel governance challenges. The findings also indicate that the risk framework is a suitable tool to guide future SAI risk management considerations. Whilst the governance model, because of its flexibility and capacity for inclusion of the perspectives of multiple interested and affected parties, provides a workable theoretical architecture.

9.5 A democratic deficit

The idea that SAI should be developed in a democratic manner has been identified as an area of debate by, for example, Macnaghten and Szerszynski (2013) who suggest existing political systems may not have the capacity to accommodate SAI because of its unique nature. However, the participants in this research suggest that concerns about a deficit may be misplaced, with many saying that it is in the nature of democracy to have some deficit and that the absence of an SAI 'opt out' was not unique, nor that it required the construction of novel politics nor governance processes. Three of them, for example, argued there had been no political system in place to underpin democratic process during the introduction of other globally changing technologies. This study, then, suggests that the expected plural governance processes would provide locations for democratic engagement. However, to be effective, it would have to be international and include those most likely to be affected by SAI and climate change in less developed countries. The scale and complexity of such participative work is very challenging. It would have to be sustained over long timeframes, and be effective in many countries with differing cultures (Buck, 2016, Dryzek et al., 2011). How this could be achieved is very much an area for further research.

9.6 Emergency narratives

As noted in section 6.6, there has been considerable debate about the role of climate emergencies in respect of decision-making about if, how, and when to develop or deploy SAI (Morton, 2015, Keith, 2013, Blackstock et al., 2009, Victor et al., 2009b). It is important to note that the emergency framing, and in particular, the uncertain space that lies between climate emergencies and multiple extreme events, clearly retained some ground amongst the interviewees.

The emergency framing gave respondents a tool with which to grip the issues and gain traction when imagining future SAI scenarios with clarity of thought. This is significant and suggests that emergency framings could be a productive narrative tool in any future research or other SAI risk and governance related work. A key, unanswered question, is whether serious consideration of SAI should begin immediately, or only in the light of accelerating numbers and scale of extreme events. The former gives an opportunity to examine the environmental, technological, political and wider governance issues in a measured, deliberative process informed by evidence and underpinned by contemporary research. The second option, as the findings indicate, is a recipe for poor governance and potentially dangerous SAI deployment, because it would not include plural, un-rushed governance processes. Key to developing such an approach would be the establishment of agreed metrics to specify a point at which sufficient extreme events have occurred to warrant deployment. Importantly, this study shows that this will be a highly contentious issue, suggesting that an early exploration of how such metrics might be agreed is required. This should, as with other areas, also be an inclusive plural discourse.

Either approach, however, raises critical questions about a slippery slope decline toward 'inevitable' deployment, and about intergenerational responsibilities. If we believe that climate emergencies are at least possible, is failure to adapt and mitigate sufficiently now, and developing SAI for the future, an acceptable moral choice?

9.7 The wider political landscape

Politicians have to-date rarely engaged in consideration of SAI. However, this does not reflect an absence of politics around SAI. The politics of chemtrails, for example, is argued to be about a distrust in, and sense of betrayal by, government (Cairns, 2013). Concerns that politics is wrapped in secrecy and conducted for incumbent interests, alongside ideas that it is becoming individualised and personal, are also shared by wider publics in the climate change debate (McLaren, 2016). For these publics a sense of justice and injustice intersects and structures their views of politics that include an increasing resistance to vested interests and profiteering among politicians, but also more widely. For example, McLaren (2016) suggests that the apparent willingness of the West to dump its rich world problems on the poorer people of the developing world is present in those public political discussions.

Different groups, identities or publics bring different conceptualisations, understandings of, and models for SAI. For some, it is a tool with which to fight significant mitigation and adaptation measures that they opposed. For others, SAI could offer a safe haven from a long-lasting, bitter and broadly unsuccessful effort to achieve meaningful mitigation and adaptation that appears to have either stalled or failed (McLaren, 2016). For others, SAI may challenge their identity, whether that be, for example, as interested and affected representatives of low lying communities vulnerable to sea-level change, or as human beings who favour living as complementary participants in the Earth ecosystem, rather than its controllers.

These issues require that political science looks beyond governance, regulation, formal institutions and partisan politics to address the broader concerns and aspirations of publics globally. The politics of SAI should increasingly become not only a politics of the technology, but also a politics that addresses a far wider set of agenda including climate injustice, identity and meaning.

9.8 Insights to the management of the Anthropocene

Chapter 3 explored similarities between the risk management and governance of SAI and the Anthropocene. Whilst the focus of this research was not to explore these issues, the findings do offer some insights into the issues flagged in the earlier discussion. Fundamental questions highlighted during the research, such as deciding about what sort of climate we want, also apply to the wider Anthropocene relevant questions about the nature of the planet that we want to live on, including topics such as the future of biodiversity, the nature of the oceans and the composition of the atmosphere.

It may be that, as with SAI, the Anthropocene would be better governed if subjected to an un-rushed, inclusive debate through which uncertainty, ambiguity and dissent are made explicit and exposed, allowing them to act as tools to create diverse, multiple possible responses suited to variable social, political, cultural and economic situations. The detached, disassociated scientific elites working to set planetary boundaries and agenda on behalf of humanity (Rockstrom et al., 2009) and discussed in section 3.6, might impede, rather than facilitate, the progression of a productive, low risk Anthropocene governance processes.

The centrality of the human in the concept of the Anthropocene demands that the social be present in its governance. It may be that, as with SAI, Anthropocene governance should not side-step uncertainty, nor should it allow science to maintain distance or independence from the social. Rather, as suggested by Baskin (2015), the social sciences should be located at the centre of Earth science, establishing new foundational grounds on which to base governance. The inclusion of social agenda brings to bear complex values, social systems, institutions and contestations of evidence and fact. These should and can be addressed although not necessarily resolved, through a careful, deliberative inclusion of dialogues about risk uncertainty, uncertainty more broadly, and, dissent. How this might be done is an important question for future research. It is proving challenging to undertake similar exercises within a single country around innovative technologies, let alone globally. Any approaches would necessarily be slow, require patience and would have to be highly flexible. However, to exclude the social and constrain messy plurality in the governance of the Anthropocene would be an error.

If the social were brought to bear, the Anthropocene might have radically important implications, not only for the sciences that are claiming a predominant role in designing the Earth, and how humanity will live on it, but also for the scientific method, the authority of physical and natural science more broadly and, the extent to which the social and political interface more widely. These are important areas for future fundamental thinking, as part of the construction of a new world conceptualisation of knowledge and meaning, in the context of a laboratory of previously unimagined size and complexity.

9.9 Conclusion

This chapter has discussed the extent to which the theoretical framework and research method delivered and demonstrates that they were both fit for purpose. A number of suggestions were made, which may be useful for future research on SAI risk and its governance, about how the method might have been enhanced to reveal more depth, including using a follow up self-validation measure and, securing a larger sample.

In light of the research a number contributions to the wider SAI debate, informed by the study, were discussed. Some generic contributions to SAI scholarship were explored regarding: the nature of SAI as a distinct technology; whether a democratic deficit will exist in its governance; how emergency narratives are constructed, and the role they played in participants' thinking about SAI deployment; and, the extent to which SAI, in the context of the findings, could inform future discussions about the governance of the Anthropocene.

The thesis concludes with Chapter 10, in which the study is reviewed and some suggestions for future research are offered.

CHAPTER 10 – CONCLUSION

10.0 Chapter overview

In concluding this thesis the rationale for the study, some of the key arguments and the theoretical framework are summarised. Following this, the methods and findings are outlined and the contribution to knowledge is described. Finally, the value of the study in the context of the existing literature and some suggestions for future research to take the agenda forward are offered.

10.1 The research questions

In the context of climate change adaptation and mitigation, it is highly timely to discuss geoengineering, as a future option (see Chapter 1). Stratospheric aerosol injection solar radiation management (SAI) was selected as the focus of the case study. Central to the research is an exploration of how risk management and environmental governance of the technology will play out, as was discussed in Chapter 2. These are examined through the lens of the two key research questions, designed in the light of the characteristics of the technology and risk and governance literatures, these were:

- how might deployment risks be incorporated into SAI governance; and,
- might SAI governance be plural?

The research is not intended to recommend whether or not SAI should be deployed, rather it exposes how risk management and governance processes may play out in the future, independently of any commitment to deploy.

The nascent SAI governance literature was reviewed in Chapter 3, establishing that there is no regulatory or informal governance *in situ* and appropriate for SAI. Whilst the literature does suggest SAI risks and their incorporation into its governance are of critical importance, to date there has been little empirical research to explore how this may, or may not, occur.

10.2 The theoretical framework

The theoretical framework, developed in Chapter 4, is underpinned by a view of governance as an organic, plural process that incorporates a wide range of interested and affected parties functioning without formal controls in place. Alongside this, risk is conceptualised as a complex idea that transcends quantitative calculations of probability and loss, to include a broad range of attributes, including uncertainty, ambiguity, incertitude and ignorance, and which recognises the importance of perceptions of risk and their effects on risk response and governance.

In the light of these conceptualisations, a risk typology and risk management model, purposefully constructed to incorporate complex understandings of risk (Renn, 2008), was selected to consider how SAI risks might be conceptualised and managed during the governance process. The thesis' theorising of SAI governance suggested that, in the light of the multiplicity of perceptions about risk and its governance, a model that would allow the incorporation of the expected divergent perspectives grounded in, for example, different contexts, public values, disciplinary perspectives and actor interests, should be used. Bulkeley's model of climate change governance (Bulkeley, 2012), which recognises the particularly important roles of consensus, consent and concord was chosen. It was expected that the model would provide a descriptive tool, with which to frame the study, rather than a strict typology of governance responses against which the research evidence would be tested.

10.3 The method

To gain insights into how knowledge, understandings, and evaluations about SAI governance are formed, it was essential that the method, addressed in Chapter 5, was sufficiently sensitive to access the complexities of the multiple contentions and actors, with divergent framings. To allow for a plurality of views and inherent uncertainties about the technology to be incorporated, a qualitative approach was selected. A number of methods were reviewed, and senior stakeholder interviews selected. Following a pilot study, the interview instruments were refined and, subsequently, 30 senior stakeholder interviews were undertaken. The sample drew from a range of interested and affected communities that had been characterised, in the context of SAI, prior to constructing the sample.

10.4 Original contributions to knowledge

The findings, presented in Chapters 6, 7 and 8, make a number of interlinked contributions to understanding how interested and affected parties frame and think about SAI risk and, how its future governance may evolve. They show that the two models of risk management and governance provide a useful tool to demonstrate how SAI might be governed.

The research shows that deployment risks are likely be incorporated into SAI governance, and they may be constructed in complex terms avoiding quantitative cost benefit approaches to decision making, in favour of more open, inclusive approaches. It is unlikely that deployment will ever be on a unilateral, single state basis nor under a global treaty or convention. Rather, the governance of SAI is likely to be plural, inclusive and conducted in an un-rushed manner. A key factor in such plural processes would be the recognition and inclusion of dissent in the governance process.

The research indicates that nation states will not operate in a hierarchical model, suggested by regime understandings of governance. Rather, it suggests, the states will function as one agent, amongst a multiple plurality of other active interested and affected parties. This finding is strongly supported by the theoretical expectation that authority within SAI governance would function as an achieved condition, rather than an assumed or extant position. The identified un-rushed governance processes, and the drivers for that, suggest it will be multiple years before any tangible commitments or institutional, economic and infrastructural attachments are made to any particular SIA deployment pathway.

There was strong support for new efforts to improve knowledge about SAI, with a linked commitment to on-going dialogue between the fullest range of parties about that knowledge creation process. Such dialogue should commence immediately and include both physical, environmental and social science research as well as wider conversations across interested and affected parties about both the research, and their responses to the technology and its potential effects. The importance placed on meaningful efforts to raise consciousness, to discuss and explore risks, and to seek to incorporate those into SAI governance by the interviewees was one of the strongest findings of the study. It demonstrates a very strong general commitment including the possibility of SAI deployment in debates about how to respond to climate change.

10.5 Implications of the findings

More joined-up thinking and engagement across the politics and science policy of SAI, geoengineering and climate change, particularly in relation to risk, are required. The study's finding that, the more intertwined the SAI debate is with a plurality of interested and affected parties, the better the quality of its governance, suggests that this widening of the conversation – particularly as the UNFCCC and IPCC increasingly discuss scenarios that include some form of geoengineering within them – would be valuable.

Scientists and engineers need to continue to work towards better ways of sharing their science, a challenge recognised in the current phase of the UK government-supported Sciencewise dialogues on innovative technologies (Involve, 2017), and they could benefit from opening up the science agenda-setting process to a wider, non-expert, community at an earlier stage. How this might be better done in relation to SAI is one of a number of areas for future research

10.6 Gaps in knowledge, future research questions

Throughout the thesis a number of topics on which further research would be beneficial have been identified. Some became clear during the review of literature, whilst others became apparent during the fieldwork and analysis. Chapter 2, the review of geoengineering options, demonstrated that there is significant scope for considerable engineering, physical, and natural science research to inform the full range of potential approaches reviewed. Briefly, in terms of SAI physical science and modelling research, the most important research issues are:

- to gain a better understanding of candidate particle behaviour in the stratosphere, and their interactions with ozone; and,
- to advanced climate modelling of the effects and impacts of aerosols, including on precipitation and warming/cooling distributions.

Outstanding engineering questions include aircraft engineering to lift sufficient payloads into the stratosphere and spraying nozzle design.

A range of interdisciplinary research questions for the social sciences have also been identified throughout the thesis. If deliberation is to be a useful tool in future SAI research, fundamental methodological research, or methodological research in the context of substantive questions about SAI, on how to better engage global publics and highly diverse interested and affected parties would be beneficial. Insights into how best to facilitate such processes, how to use their products, and share those in effective ways to contribute reflexively to SAI governance dialogue, would make a significant contribution.

Longitudinal qualitative research into people's knowledge and attitudes towards SAI could helpfully inform how to forward SAI conversations as understandings about the technology, and its effects, change over time. If SAI research does accelerate the tracking of changes in knowledge or attitudes, in the light of an evolving technology and improved evidence about its environmental effects, this could make an important contribution to the development of good governance. If such studies are undertaken, they should be internationally inclusive to secure insights from across different cultural perspectives. This inclusivity is key because research on how diverse cultures view and interpret SAI has been lacking in the SAI governance literature, other than within the SRMGI. Given the incertitude associated with the technology, and its effects, there could be value in using surrogate technologies as indicators of potential public responses to SAI, as an intermediate tool. Such work would make an important contribution to the construction of a wider, more plural, governance debate identified as important in this research.

SAI literature (NERC, 2011), and participants in this study, both suggest that increasing public discussion about SAI should be expected and that those engaged in the debates may change their personal climate-change mitigation behaviours. Research to explore whether there is any causal link between discussing SAI and mitigation behaviours would be useful. Such work should also explore if any 'rebound effect' occurs (Chakravarty et al., 2013): i.e., a scenario in which those discussing SAI take confidence from the promise of the technology and increase their environmentally harmful habits and practices.

The absence of the media as an actor in the dialogue about SAI risk was interesting (see section 7.9) and, given the role the media played in the SPICE project, it is perhaps surprising too. Further research on how media might engage in, respond to, and interplay with others in the appraisal of SAI would therefore be useful.

Given the role of emergency narratives in the construction of respondents' perspectives, plus opacity among respondents' interpretations of what an emergency, or a sufficiency of extreme events is, new research should explore their meanings. This would inform future considerations of SAI deployment timelines or processes, and contribute to the understanding of perceptions of climate extreme events and thresholds of change that impact public response.

There is a dearth of research on the wider politics of SAI. Research on the interrelationships between SAI and climate change politics would be particularly useful. For example, evidence about how signatories to the UNFCCC would view the inclusion of SAI research evidence within IPCC frameworks would help construct better lines of sight about how climate change and SAI may, or may not, be brought closer together.

The atmosphere is broadly ungoverned. Research on whether and how the atmosphere, as a global commons, might be governed will be critical for SAI progress. This research should explore conceptualisations of the atmosphere and recognise that, with SAI, it will become a new area of enclosure and contestation with an important influence on humanity. Whether that reconceptualisation will demand new theoretical and framing devices to shape research about it, is in itself, a research question.

Finally, SAI and geoengineering research raises important questions about the social sciences themselves. Unlike other technological developments, such as nanotechnology and GMO, social science research about values, meanings and governance of geoengineering is taking place in advance of the technologies' development. The social sciences have argued in favour of their early inclusion for a long time. SAI is now providing a real world opportunity for social science to do this and to examine fundamental questions such as 'what is a good planet?', 'what do we wish the role of global technologies to be in our lives?' and, 'what are the implications of SAI and other technological interventions on social justice?'. The most important remaining SAI research question may be, 'can social science deliver on its claim that, social science is critical to responsible technological innovation?'

ANNEXES AND APPENDICES

Annex 1

The Haida Gwaii 'geoengineering' experiment

Iron fertilisation, whilst under researched, is occasionally deployed. One particular intervention offers an interesting case study into how interested and affected parties can respond to geoengineering.

In 2007 the American company Planktos started selling carbon offsets on its web site, claiming that an initial ocean fertilization test, conducted off the coast of Hawaii from the private yacht of singer Neil Young, was taking carbon out of the atmosphere (ETC, 2012). In 2008 Planktos announced that plans to dump tens of thousands of pounds of iron particles across 10,000 square kilometres of international waters, near the Galapagos Islands, had been cancelled due to a lack of funding.

A more recent example provides insight into how reactions to geoengineering can play out. In 2012 Haida Gwaii, a small remote community in the North Pacific rainforest archipelago off the coastline of Prince Rupert Columbia became subject to global news after the Guardian newspaper headlined a story 'World's Biggest Geoengineering Experiment 'Violates' UN Rules' (Lukacs, 2012). However, what the community had been attempting was ostensibly to enhance the environment in an attempt to improve declining salmon stocks by adding iron to 'fertilise' the ocean increasing the plankton biomass, which in turn, so the community believed, might increase salmon abundance.

The Haida Salmon Restoration Corporation, a private company, released 120 tonnes of iron sulphate in to an ocean eddy 400km offshore. The link with geoengineering was made because the project was linked to Russ George, an entrepreneur with a history of contentious carbon credit start-ups (Buck, 2014). This was flagged to the media when the technology watch-dog, ETC Group, contacted the international press to alert them to the work, flagging it as geoengineering. This reporting coincided with the UN's Convention on Biological Diversity Conference of Parties in

India (CBD COP 11), in which the ETC Group were presenting a case for a test ban on geoengineering (ETC, 2012). Horton commented that the combination of the ETC Group aligned with like-minded reporters had, in effect, orchestrated a scandal timed to coincide with the CBD COP (2012). In May 2013 George was removed as lead of the project and the Community announced the project's cancellation. Within the scientific community, some geoengineering researchers seriously criticised the project; David Keith, for example, called it "hype masquerading as science" and parties to the London Convention/London Protocol released a statement of condemnation in November 2012 (Hume, 2012). Contiguous with the Haida experiment, the governing body of the London Protocol tasked its Ocean Fertilization Working Group to develop options for providing a control and regulatory mechanism for ocean fertilization and, on 18 October 2013 the Protocol Parties, added a new article (6bis), which effectively banned iron fertilisation geoengineering, stating that "Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering" (LC&P, 2015).

The Haida project raised a range of issues such as:

- who decides what is and is not legitimate science and from where does that legitimacy come – regulatory bodies, experimental designers, funders or commentators for example;
- who and by what mechanisms do institutions keep control of science when equipment, funding and information is broadly available; and,
- how can geoengineering governance and environmental governance be disentangled, by whom and to what effect?

The international, negative response to the project stems not only from concerns about the governance of science, but also from the uncertainty about the potential environmental consequences of iron fertilisation. Wallace et al (2010) reviewed the consequences noting a range of unintended and mostly undesirable impacts including:

- the production of climate relevant gases, that could potentially reinforce or offset the benefits of any carbon sequestration achieved;
- far-field effects on ocean productivity;
- mid-water oxygen decrease;
- shifts in patterns of ocean acidification; and,
- detrimental effects to the sea bed and the seafloor ecosystem.

Annex 2

University Ethics Approval – Pilot Study

From: ERGO [ergo@soton.ac.uk]

Sent: Friday, February 20, 2015 4:47 PM

To: Rouse P.I.

Subject: Your Ethics Amendment (Ethics ID: 13766) has been reviewed and approved

Submission Number 13766:

Comments

1. Excellent application. Good luck with your research.

This email is to confirm that the amendment request to your ethics form (RISK IN THE GOVERNANCE OF THE ANTHROPOCENE. HOW MIGHT THE GLOBAL COMMONS BE GOVERNED IN A GEOENGINEERED WORLD? (Amendment 1)) has been approved by the Ethics Committee.

You can begin your research unless you are still awaiting specific Health and Safety approval (e.g. for a Genetic or Biological Materials Risk Assessment)

ERGO : Ethics and Research Governance Online

http://www.ergo.soton.ac.uk

University Ethics Approval – Main Study

From: ERGO [ergo@soton.ac.uk]

Sent: Friday, October 23, 2015 5:48 AM

To: Rouse P.I.

Subject: Your Ethics Amendment (Ethics ID:17683) has been reviewed and approved

Submission Number 17683:
This email is to confirm that the amendment request to your ethics form (RISK IN THE GOVERNANCE OF THE ANTHROPOCENE. HOW MIGHT THE GLOBAL COMMONS BE GOVERNED IN A GEOENGINEERED WORLD? (Amendment 2)) has been approved by the Ethics Committee.

You can begin your main phase of research unless you are still awaiting specific Health and Safety approval (e.g. for a Genetic or Biological Materials Risk Assessment)

ERGO : Ethics and Research Governance Online

http://www.ergo.soton.ac.uk

Appendix A to Annex 2

Participant Information Sheet

Study Title: **RISK IN THE GOVERNANCE OF THE ANTHROPOCENE. HOW MIGHT THE GLOBAL COMMONS BE GOVERNED IN A GEOENGINEERED WORLD?**

Researcher: **Paul Rouse** **Ethics approval reference**: **17683**

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This is an independent, Economic and Social Research Council UK funded PhD research project under the supervision of Professors Will Jennings, Judith Petts and John Shepherd at the University of Southampton, UK. It aims to examine how the governance of global commons may play out in the context of risks associated with stratospheric aerosol injection solar radiation management geoengineering (SAI). SAI will be used as a case study to explore stakeholders' perspectives, positions and roles in governance.

Governance is a widely used term and can mean different things to different people. In the context of this interview governance is defined as follows.

Governance refers to the entire process of defining, developing, engaging, deliberating, negotiating, establishing, implementing and reviewing the oversight for SAI. These processes can happen within and between many spheres, for example the public and private, scientific and political, ethical and practical, moral and economical. In other words, governance in this context is about the interactions between these multiple processes.

A number of individuals are being interviewed to to secure high level insights to SAI environmental governance issues and agenda. The two key research questions being addressed are:

how might deployment risks be incorporated into SAI governance; and,

might SAI governance be plural?

Why have I been chosen?

You have been selected as an individual with environmental interests who operates in one of the following stakeholder groups:

science institutes;

government departments/bodies;

NGOs or other interested parties;

global institutes;

corporate interests; and,

academics.

What will happen to me if I take part?

If you agree to participate in the study we will find a convenient time to meet for the interview at your place of work or by telephone. The interviews will take approximately one hour. Before commencing the interview we will discuss the process in some detail to ensure you are comfortable with proceeding, after which you will be asked to complete a consent form.

The interview will be recorded, digitally stored and transcribed. Your anonymity will be assured. Participants' names will be coded and those codes will not be disclosed in any reports, publications, correspondence or other communications.

Pseudonyms will be used for all individuals referred to in transcripts and all other research output. Whilst individuals will be anonymised it will be critical to the project's success that the general type of organisation is revealed, for example 'Scientist', 'Non-Governmental Actor' etc. However, names of organisations or institutions will not be disclosed at any time. I will explore with you what descriptor would be acceptable to you during the interview.

Information about confidentiality and data protection is provided below.

At the conclusion of the interview you will be reminded of: how the data will be stored; used; and, your right to withdraw from the study. The remaining stages of the research will be explained.

Finally, you will be asked if you have any last questions or comments and be thanked for participating in the research before the interview ends.

Are there any benefits in my taking part?

You will receive a summary of findings and will be offered the opportunity to discuss these at the end of the project. If you would like a full copy of the final thesis that will also be provided.

Are there any risks involved?

There are no risks.

Will my participation be confidential?

All interview and pre interview data will be kept in accordance with the Data Protection Act, the Freedom of Information Act and the University of Southampton's Data Protection policy (http://www.southampton.ac.uk/inf/foi.html).

Data and qualitative material will be stored in password protected areas on the University server and the researcher's laptop. The material and data that could allow the identification of participants will only be accessible by the researcher and supervisor. If the supervisor accesses the data, a record of each time and date of access will be kept by the researcher. The University Enabling Services Unit staff will transcribe the interview. The recordings will be supplied to them in an anonymised form, using a unique identifier code for each interview subject. The staff are employed by the University of Southampton and their contract includes a confidentiality clause. It would be a breach of contract for them to reveal any information provided. They are also bound by the University's Data Protection

Policy. The LSAs will be reminded of these obligations when they start the work. The transcribers will confirm in writing that they have deleted all copies of the materials when they return the transcriptions.

If you wish to review the data held about you I will make this available to you electronically or in print within 10 working days of any request.

What happens if I change my mind?

You are at liberty to withdraw from the study at any time and your legal rights will not be affected. If you choose to withdraw from the study you will not automatically receive the summary of findings.

What happens if something goes wrong?

If you have any concerns or complaints, please contact the Chair of the Faculty of Social and Human Sciences Ethics Committee, Dr Schroeder-Butterfill, Building 58, Highfield Campus, University of Southampton, SO17 1BJ. Telephone (023) 8059 6880 Email: E.Schroeder-Butterfill@soton.ac.uk

Where can I get more information?

If you have any remaining question please contact me by telephone on 00 44 (0) 1672 841296 or by email at pir1g12@soton.ac.uk.

My lead supervisor can be contacted at: Prof. Will Jennings, Politics & International Relations, Room 58/3067, Highfield Campus, University of Southampton, SO17 1BJ. Telephone: (023) 8059 3998 Email: W.J.Jennings@soton.ac.uk

Appendix B to Annex 2

CONSENT FORM

Study title: **RISK IN THE GOVERNANCE OF THE ANTHROPOCENE. HOW MIGHT THE GLOBAL COMMONS BE GOVERNED IN A GEOENGINEERED WORLD?**

Researcher name: **Paul Rouse**

Ethics reference: **17683**

Please initial the boxes if you agree with the statement(s):

I have read and understood the information sheet dated October 2015, and have had the opportunity to ask questions about the study. ☐

I agree to take part in this research project and agree for my data to be recorded and used for the purpose of this study. ☐

I understand my contributions will be anonymous and no responses will be identified with me personally. ☐

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected. ☐

Data Protection

I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study.

Name of participant (print name):

Signature of participant:

Date:

Annex 3

Pilot Study Interview Schedule

Question 1	Who might deploy SAI?
Question 2	Under what circumstances might deployment take place?
Question 3	How do you characterise risk?
Question 4	What are the risks of deployment?
Question 5	Which stakeholders will be actively involved in SAI governance?
Question 6	What principles of risk governance would be important?
Question 7	How do you think these principles would be used in the protection of the global commons?
Question 8	Will stakeholders seek to resolve uncertainties about the risk of deploying SAI, how and with whom?
Question 9	Can an intolerable risk become tolerable, if so how?
Question 10	Under what conditions might stakeholder dialogue lead to jointly agreed decisions?
Question 11	How and under what conditions could actions be taken, without causing serious dissent, to effectively govern the global commons?
Question 12	How can contestation be most effectively resolved amongst stakeholders?
Question 13	How and under what conditions can stakeholders make their presence felt in the processes?
Question 14	How likely is it that participative governance processes will take place before deployment occurs?
Question 15	Which approach to deployment that we've discussed would deliver the best outcome?

Annex 4

MAIN STUDY INTERVIEW SCHEDULE

PART I. HEADLINE QUESTIONS.

Practical and risk issues

1. Who might deploy SAI?
    a) *If say military ask why, in what form and to what effect. Would it be an 'attack' or 'defensive' military tool?*

2. Under what circumstances might deployment take place?
    b) *If say in emergency – what is an emergency, why?*

3. How do you characterise risk?
    c) *Can risk have positive connotations?*

4. What are the risks of deployment?

Governance issues

5. What principles of risk governance would be important?

6. Which stakeholders will be actively involved in SAI governance?
    Probe how the role of global institutions is viewed.

PART II. EXPLORING ISSUES SUGGESTED BY THEORY.

Risk management questions

7. Will stakeholders seek to resolve uncertainties about the risk of deploying SAI, how and with whom?

8. Can an intolerable risk become tolerable, if so how?

9. Could SAI deployment ever be acceptable?

10. Under what conditions might stakeholder dialogue lead to jointly agreed decisions?

    a) *If appropriate explore consensus consent and concord.*

Governance questions

11. How and under what conditions could actions be taken, without causing serious dissent?

12. How can contestation be most effectively resolved amongst stakeholders?

13. How and under what conditions can stakeholders make their presence felt in the processes?

Timing

14. How likely is it that participative governance processes will take place before deployment occurs?

15. Are intergenerational issues important when considering SAI governance?

Outcomes

16. Which approach to deployment that we've discussed would deliver the best outcome?

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