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An Examination of Emerging Public and Expert Judgments of Solar Radiation Management

by

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Abstract

Solar Radiation Management (SRM) is a proposed climate intervention that masks anthropogenic climate warming by reflecting a small amount of sunlight. One possible method to achieve this cooling is through the continual injection of sulphate aerosols into the stratosphere. This would cool the planet quickly and cheaply, but also pose numerous physical and socio-political risks. At the outset of this dissertation, there was limited empirical research on opinions and judgments of SRM. This thesis examines criteria influencing its acceptability, through two studies: 1) the first quantitative evaluation of international public opinion on SRM, and 2) an evaluation of expert trade-off judgments of climate responses, including SRM. Results from an online survey of 3105 nationally-represented individuals of the United States, Canada and the United Kingdom suggest that awareness of SRM in public audiences is low, but growing. Support for SRM is associated with optimism about scientific research, a valuing of SRM's benefits, and a perception that SRM is natural. Opposition to SRM is associated with an attitude that nature should not be manipulated. Individuals expressed concerns with: trusting the science of SRM; future control and governance of the technology; knowledge limitations; and distribution of harms and benefits. The sampled opinions are just forming and sensitive to changes in framing, future information, and context. The results of an online expert survey of 43 climate experts provided contextualized trade-off judgments between climate responses e.g. mitigation, SRM, and adaptation. SRM was consistently ranked as the lowest preference, despite high estimates of its effectiveness at managing temperature rise, and reducing ecosystem impacts and human vulnerabilities. Mitigation and efficiency measures were widely preferred responses, despite low assessments of their effectiveness. Assessments of SRM were characterized by large

variability. Overall, nine criteria for acceptability of SRM were identified: perceived effectiveness of mitigation; extent and quality of the intervention; level of social trust; perceived benefits; perceived risks; perceived naturalness; perceived control; perceived uncertainty; and perceived climate threat. Judgments about the acceptability of SRM are being made on a wide set of criteria, as such, there is no unifying public or expert opinion of SRM.

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List of Symbols and Abbreviations

Acronym / Symbol	*Definition*
BAU	Business-as-usual
CDR	Carbon dioxide removal
CO_2	Carbon dioxide
ENMOD	Environmental Modification Convention[1]
GDP	Gross domestic product
GHGs	Greenhouse gases
H_2SO_4	Sulphuric acid
IPCC	Intergovernmental Panel on Climate Change
HDI	Human Development Index
pH	A measure of the acidity or basicity of an aqueous solution
SO_2	Sulphur dioxide
SPICE	Stratospheric Particle Injection for Climate Engineering
SRM	Solar radiation management
Tg	Teragram (e.g. Tg S/yr is a teragram of sulphur per year)
UNFCCC	United Nations Framework Convention on Climate Change
W/m^2	Measure of radiant remittance - watts per square meter

[1] Formally the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques

CHAPTER 1: INTRODUCTION

1.1 The mechanics of climate change

The Earth's temperature is the product of the equilibrium between incoming solar energy (shortwave radiation) and out-going thermal energy. Each day, the Earth absorbs radiant energy from the Sun. This warms the atmosphere and surface by converting short-wave radiation into heat (infrared radiation) (Kiehl *et al.*, 1997). Carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere absorb and re-emit infrared radiation until the incoming and outgoing fluxes balance. Human activities including burning fossil fuels and land use changes have increased the concentration of atmospheric GHGs. This has made it harder for the Earth to radiate infrared heat thereby increasing global temperatures in a process called climate change.

Radiative forcings are perturbations in the Earth's energy fluxes. At equilibrium, the average net radiation is zero, but a change in either the solar energy or infrared radiation changes the net radiation. Agents of these perturbations are considered to be either positive, e.g. greenhouse gases, resulting in Earth warming, or negative, e.g. higher atmospheric reflectivity, resulting in Earth cooling. Radiative forcing is expressed as the energy perturbation introduced into the Earth's fluxes (W/m^2). The anthropogenic increase in radiative forcing from all GHGs is 2.83 W/m^2 [2.54 to 3.12 W/m^2] of which, 1.82 W/m^2 [1.63 to 2.01 W/m^2] is from the anthropogenic increase of CO_2 (IPCC, 2013b). This positive perturbation of the energy flux has resulted in a warming of 0.13°C [0.10 to 0.16°C] per decade[2] (IPCC, 2007d).

1.2 A case for stopping climate change

Estimates by the Intergovernmental Panel on Climate Change (IPCC) suggest that a doubling of atmospheric CO_2 (which causes about a 4 W/m^2 positive radiative forcing), will result in an

[2] 50 year trend from 1956 to 2005

estimated 3°C [1.5 to 4.5°C] increase in global average temperature (IPCC, 2013b). The direct results of this rise include:

- melting of ice caps, glaciers and permafrost;
- rising sea levels caused by the thermal expansion of water and the melting of ice sheets;
- changes in regional precipitation patterns (increasing in higher latitudes, and decreasing in subtropical land regions);
- increasing climate variability;
- increases in frequency and severity of extreme weather events - e.g. hurricanes, floods and droughts; and
- increasing frequency, intensity and duration of heat waves (IPCC, 2007a; Houghton, 2009).

Higher levels of atmospheric CO_2 also result in a shift of the oceanic-atmospheric equilibrium such that the ocean will uptake more CO_2 causing it to become more acidic.

The impacts from these physical responses of unabated climate change are estimated to cost about 5% of global gross domestic products (GDP) per annum (Stern, 2007). These impacts include threats to livelihoods and security due to rising sea levels and increased storm surges, reductions in some crops' productivity due to heat stress (Lobell *et al.*, 2011), and shifting animal and plant habitats due to precipitation and temperature changes, and losses of coral reefs due to ocean acidification (Houghton, 2009).

Prior to any further discussion about climate change, it is important to explicitly state a basic operating principle underlying climate discussions. The United Nations Framework Convention on Climate Change (UNFCCC) Article 2 states there is a need to stabilize the atmospheric GHG concentration to avoid "dangerous anthropogenic interference." This requires

further clarification. The Earth, on geological timescales, has experienced large changes to its energy flux from its relative proximity to the Sun and its historical atmospheric concentration (IPCC, 2007c). This has resulted in major shifts in the physical environment on the planet, ranging from the ice ages of the Cryogenian period to warm periods such as the Pliocene Era. This physical response has no normative dimension. What is "dangerous" about climate change requires answering questions like: Dangerous to who? What impacts do we consider? and On what timescales? In the UNFCCC, adverse effects of climate change are defined as,

> Changes in the physical environment or biota resulting from climate change, which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare (Article 1).

An effect from climate change can be quantified (to the extent possible) through scientific observation of the physical response, however, labeling a change as deleterious is ultimately based on value judgments. And by extension, policies to limit climate change are based on our normative understanding of dangerous. Exploring these judgments and opinions provide insight into current climate policy.

1.3 Options for a climate response

Until recently, responses to climate change have centred on two fundamental strategies: stopping or slowing carbon emissions[3] – called mitigation – or adjusting human lifestyles in response to a warmer climate – called adaptation. Another possible solution, considering only the Earth's energetics, would be to introduce a negative radiative forcing into the system to countervail the positive forcing from GHGs. Such a negative forcing could be obtained from *reducing* the solar energy delivered to the Earth's surface through increases in its overall

[3] Carbon emissions are the largest contributor to the increase in anthropogenic radiative forcing.

reflectivity, or albedo.

Table 1.1 presents the breadth of options currently available to address climate change. These are not mutually exclusive, but rather a portfolio that may work in different contexts, as illustrated in Figure 1.1. To limit climate change, emissions must be mitigated through a global reduction in production and consumption (Anderson *et al.*, 2006; Royal Society, 2009). Policy "gridlock" plaguing the international, national and regional debates has severely limited the mitigation response to date (Victor, 2011) and emissions rates have continued to grow (IPCC, 2013b). Even if it were possible to stop all carbon dioxide emissions today, the portion of the CO_2 that is present in the atmosphere would remain active for centuries to millennia before it equilibrates into carbon sinks (Archer *et al.*, 2009). Over this time period, CO_2 continues to exert a positive radiative forcing. While conservation, efficiency and low-carbon energy may limit future emissions, the current atmospheric concentrations have long-lived effects. It is within this policy context that geoengineering, which is an active intervention into the climate system, is being considered.

Table 1.1 Definition and examples of climate responses available to humans wishing to limit deleterious impacts of anthropogenic climate change

	Conservation	***Efficiency***	***Decarbonization***	***CDR***	***SRM***	***Adaptation***
Definition	*Actions that reduce consumption of energy services*	*Actions that maintain the same service output with less energy use*	*Actions that reduce energy system emissions per unit of energy delivered*	*Actions that increase carbon dioxide sinks*	*Actions that seek to reduce solar radiative forcing*	*Actions that seek to reduce vulnerabilities to climate change impacts*
Specific Examples	- Eating less meat - Flying less	- Decreasing end-use electrical requirements of equipment (from small household appliances to industrial equipment) -Reducing energy losses (co-generation, transmission line improvements)	- Reducing carbon intensity of energy sector (through fuel switching, increased renewable energy source, nuclear energy use, carbon capture and storage)	- Directly capturing and sequestering carbon from the atmosphere - Fertilizing the ocean with limited nutrients to increase primary production	- Injecting sulfate aerosols into the atmosphere to reflect solar radiation - Increasing the albedo of the earth's surface through modification of land surfaces	- Building port infrastructure to accommodate higher sea levels. - Changing crop mixtures to address different precipitation patterns

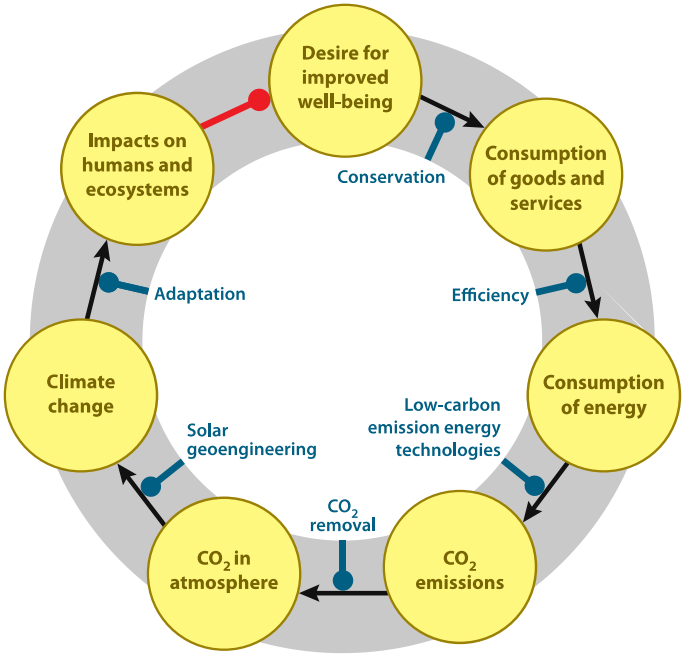


Figure 1.1 The potential human responses to climate change and the contexts in which they work. Reprinted courtesy of Calderia *et al.* (2013).

1.4 A case for solar radiation management

Chapter 2 explains both carbon dioxide removal (CDR) and solar radiation management (SRM) interventions in detail, however, for now I will focus on the topic of this thesis: SRM. In brief, SRM technologies propose to increase the Earth's albedo to reflect a small proportion of inbound solar energy, thereby cooling the planet. One of the most frequently discussed interventions would involve continual injections of sulphate aerosol droplets (which are known to be very reflective) into the stratosphere. This would mimic the natural cooling effect that occurs when large volcanic eruptions send millions of tons of sulphates into the stratosphere.[4] SRM interventions would not directly address the cause of climate change, but rather seek to

[4] The layer of the atmosphere starting on average 11 km and extending to 50 km above the Earth's surface. At the poles it starts at about 8 km altitude, and at the equator around 18 km.

mask the warming. SRM might provide a policy option that is not currently available to policymakers, as it has the unique potential to reduce the rate of global warming, or even cool the planet, both quickly (Caldeira *et al.*, 2007; Robock *et al.*, 2008) and cheaply (NAS, 1992; Barrett, 2008; McClellan *et al.*, 2012). This is something that mitigation, adaptation or CDR could not realistically achieve. Despite this, SRM is an imperfect method for addressing climate change. It is likely to be associated with numerous physical and socio-political risks, and it will not address the root cause of the warming: increasing atmospheric GHG concentrations (Keith *et al.*, 1992; Keith, 2000; Crutzen, 2006; Robock, 2008; Blackstock *et al.*, 2009; Royal Society, 2009; Corner *et al.*, 2010; Keith *et al.*, 2010).

If SRM is associated with considerable risks and major uncertainties, why pursue this path at all? Given the difficulties with making meaningful carbon reductions, and the centennial time-scale impact of CO_2, SRM has been proposed as: 1) a near-term tool in a broader climate strategy aimed at reducing the social cost of climate change (Wigley, 2006); and/or 2) an immediate crisis intervention that may be used in the event of a 'climate related emergency' (Blackstock *et al.*, 2009). The first application frames SRM as a useful tool for near-term climate stabilisation, while major mitigation is undertaken, effectively shaving off a temperature peak (Wigley, 2006). The second proposes SRM as an insurance policy in the event of a climate emergency (loosely defined as a climate response that reaches a deleterious threshold). This "plan B" condition frames SRM as a tool to be used in a temperature-related tipping point, such as a collapse of the Greenland Ice Sheet. Keith *et al.*, (2010: 426) contend that SRM "may be the only human response that can fend off rapid and high-consequence climate impacts." The speed and low cost of SRM makes this technology very different from mitigation or adaptation.

Article 3.3 of the UNFCCC instructs, "policies and measures to deal with climate change should be cost effective so as to ensure global benefits and lowest possible cost." Crudely summarized:

- *mitigation* is expensive, requires global cooperation and is largely ineffective at harm reduction in the short-term;
- *adaptation* recognizes that climate impacts and associated human suffering is inevitable, and attempts to minimize them, sometimes at great social and fiscal cost;
- *SRM* reduces certain climate impacts, quickly and relatively cheaply.

Under Article 3.3, SRM could be the preferred course of action as it likely has large climatic benefits for little cost. For many, however, SRM is neither preferred nor an acceptable policy choice. This thesis will explore the factors influencing the acceptability judgments of SRM and lend insight into the range of early attitudes and perceptions of this technology.

The remainder of this chapter will outline the key objectives and significance of this dissertation; provide an overview of the two research studies included in this thesis; and present an outline of the subsequent chapters.

1.5 Significance and Contributions of this Research

The primary purpose of this thesis is to **investigate early judgments of SRM in both lay and expert populations.** The key research objectives of this thesis include the following:

1. To investigate factors that may contribute to lay people's current attitudes and opinions of the technological acceptability of SRM.
2. To explore how climate experts characterize the decision context for a future climate strategy and the potential role of SRM.

These objectives were conceived in response to a lack of empirical data informing the key determinants that underlie early opinions of SRM. At the outset of this doctoral work, the SRM policy debate was emerging quickly, but little was known about the range of opinions in the lay population (non-technical public). It was hypothesized that the acceptability of geoengineering, "[would] be determined as much by social, legal and political issues, as by scientific and technical factors" (Royal Society, 2009: xi). Experts engaged in these conversations were left in a position to provide hypotheses about technological acceptability and lay people's potential concerns. My first research objective was designed to fill this information gap. I argued (as a co-author in an opinion piece in *Climatic Change)* that exploring and engaging lay perspectives:

> …can contribute to the research, development, and governance of one branch of geoengineering, solar radiation management, in three key ways: 1. by fulfilling ethical requirements for the inclusion of affected parties in democratic decision making processes; 2. by contributing to improved dialogue and trust between scientists and the public; and 3. by ensuring that decisions about SRM research and possible deployment are informed by a broad set of societal interests, values, and framings (Carr *et al.*, 2013: 567).

The second objective concerning experts' judgments was motivated by the central role that this group of stakeholders occupies in the greater SRM debate. These objectives were designed to explore a contextual examination of the factors influencing trade-off judgments between SRM and other climate responses. There is disagreement within this group concerning the technology's feasibility, usefulness and role. The research presented herein is intended to give greater insight into the variety of opinions. Researching lay judgments on such a new technology is a challenge because opinions are labile and often under-informed. Well-selected

experts, however, have deep technical and scientific literacy in the area allowing for a sampling of opinions that are more fully informed.

1.6 Overview of the Dissertation

This dissertation is organized into five chapters. The first two serve as background for the following two chapters, which present original research into judgments of SRM. Chapter Two introduces the current technical understanding of geoengineering. I provide an overview of both CDR and SRM technologies, focusing primarily on the latter. I summarize the feasibility and effectiveness of stratospheric sulphate aerosols, and provide a description of the potential climatic responses and the impacts on temperature, precipitation and ocean acidification of SRM use. I argue that intentionally injected stratospheric sulphate aerosols shift humanity's relationship with the planet into one where we become active managers of our global environment. This is an unprecedented and novel position with a host of ethical, political and moral implications, which are also introduced in this chapter.

Chapter Three explores the literature on technological acceptability and decision-making. I present relevant literature on three dimensions of acceptability: technology-specific, implementation and contextual. In each, I summarize findings that influence perceptions of acceptability, focusing, wherever possible, on findings specific to emerging technologies. I conclude this chapter with a brief discussion of methodological challenges of researching attitudes in an area of low awareness, namely constructed preference.

Chapter Four presents an analysis of a national representative survey of public members in Canada, the United States and the United Kingdom. The data was collected in the Fall of 2010. The first portion of the chapter is a reprint of the manuscript entitled: "Public understanding of solar radiation management," published in *Environmental Research Letters* in

2011. It characterizes the emerging support and opposition groups to SRM. Subsequently, I present a qualitative analysis of the final open-ended question in the survey, which asked: 'If you had the chance to talk to solar radiation management researchers and decision makers, what would you say or ask?' I outline seven themes raised by participants when answering this question. This work is a portion of the analysis that was published as a chapter entitled "Public concerns about the ethics of SRM" in *Engineering the Climate: The Ethics of Solar Radiation Management*. Finally, this chapter concludes with an examination of the broader developments in understanding SRM that have taken place over the course of this dissertation.

Chapter Five presents the results from a mixed methods expert elicitation, spanning from the fall of 2012 to the summer of 2013. This chapter provides an analysis of expert judgments of future climate strategies, including the consideration of SRM inclusion in a broad strategy. I outline the preferences for SRM in the context of other strategies and factors influencing its consideration. Survey tools for both studies are included in the Appendix A and B respectively.

This dissertation is concluded in the Chapter Six with the discussion of nine overall factors that influence the perception of SRM acceptability. It presents some areas for further research and final reflections on studying SRM.

CHAPTER 2: TECHNICAL ANALYSIS OF GEOENGINEERING

2.1 Introduction

Keith (2000: 259) observed, "there is a fundamental difference between controlling CO_2 and controlling its effects." Lowering carbon concentrations removes the positive radiative forcing and thereby controls the physical cause of climate change. Controlling the effects of CO_2 - through reducing insolation (measure of solar radiation on a set surface area) - means that the underlying positive radiative forcing remains unchanged. If the control mechanism, i.e. SRM, were to be removed, the original positive forcing from the GHGs would still be present, and no longer masked. The Earth's climate would adjust to this change in the energy balance, and temperatures would rise.

Changes to the Earth's radiative energy fluxes – either by increasing outgoing thermal radiation through CO_2 removal or by decreasing the absorption of solar energy through albedo modification - will ultimately change the climate and reduce the global average temperature. This chapter will focus on two geoengineering approaches that address these energy fluxes. In the first section of this chapter, I provide a brief overview of a suite of techniques used to remove atmospheric carbon dioxide. The second section of the chapter presents the current technical and scientific understanding of solar radiation management. I examine several physical, economic, political and social factors that may influence its development and acceptability.

2.2 Carbon dioxide removal

In general terms, carbon dioxide removal (CDR) techniques make use of photosynthetic, chemical or geological processes to remove and sequester atmospheric carbon (Royal Society, 2009). The overarching goal of CDR techniques is to remove CO_2 from the atmosphere, thereby

limiting thermal re-radiation. Each technology must accomplish two things: capture carbon from the air, and sequester it on a geological timescale. Currently, CO_2 removal technologies are divided by their use of two distinct pathways: ocean or land-based (Royal Society, 2009).

- Ocean sequestration involves 'seeding' biomass growth in plankton and algae by artificially increasing the availability of limited nutrients, namely iron or nitrogen. This increases primary production, resulting in uptake of carbon (Lampitt *et al.*, 2008). The carbon-rich biomass is then sunk into the depths of the ocean, where it is theoretically isolated from the climate system (Royal Society, 2009).
- Land sequestration includes: land use management (afforestation and reforestation); biochar and biomass sequestration; enhanced weathering; and carbon capture and storage directly from the atmosphere (Royal Society, 2009).[5]

CDR and mitigation are slow to produce climatic effects (Keith *et al.*, 2006) detectable on a decadal to centennial scale (Keith, 2009; Royal Society, 2009). Therefore, these techniques do not enable rapid climatic intervention.

Most CDR techniques are limited by economic barriers, namely the land and/or energy requirements to capture and store the carbon (Royal Society, 2009).[6] Impacts from CDR

[5] Carbon capture commonly called carbon, capture and sequestration from an industrial flue stack is not geoengineering. Although the technologies may share similar features, the former approach may be thought of as industrial carbon management (Keith, 2000). The difference is that direct capture from the atmosphere has the theoretical ability to lower the overall carbon concentration of the atmosphere, whereas carbon capture from an industrial flue will stop only future industrial emissions. Consequently, in industrial carbon management schemes the carbon concentration in the atmosphere remains unchanged (Keith, 2000).

[6] For example, direct air capture is an industrial process that removes CO_2 from air, through alkaline or solid state industrial absorption processes, to produce pure CO_2 streams for disposal or use. There is a high thermodynamic barrier for extraction (Keith, 2009), and since there is a low ambient concentration of CO_2 in the Earth's atmosphere, to capture sufficient carbon there is a requirement for large volumes of air to pass through the absorbing system (Holmes and Keith, 2012). These technical requirements make direct capture costly. Cost ranges vary widely (and are hotly contested). At the low end Holmes and Keith (2012) report $60 per tonne of CO_2, while the American Physical Society (2011) suggests that the cost is likely to be $600-800 per tonne. The comparative affordability of

techniques are largely associated with the manner of carbon storage and are generally localized to the area of use (Royal Society, 2009). The important exception to this would be ocean fertilization, which at a deployment scale would have transboundary implications in the ocean. Localized impacts means that CDR technologies are likely to be controlled at national and regional levels, and require less international cooperation than SRM.

2.3 Solar radiation management

At the most basic level, SRM reflects sunlight prior to its absorption, offsetting the positive radiative forcing caused by increasing atmospheric carbon concentrations (Budyko, 1977; NAS, 1992; Crutzen, 2006). Whether through mirrors in space or changes in atmospheric composition, if there is less sunlight, there will be less thermal radiation. This energetics change has a rapid effect on the global temperature, with observable cooling likely to be felt within months (Matthews *et al.*, 2007). It is because of its potential to produce a strong, worldwide negative forcing, both quickly and cheaply, that SRM is being considered. It is not, however, a perfect substitute for mitigation (Caldeira *et al.*, 2008; Robock *et al.*, 2008; Heckendorn *et al.*, 2009; Keith *et al.*, 2010).

Within the natural Earth system, the Sun's energy is reflected by surfaces such as ice, certain particles in the atmosphere and clouds. SRM approaches propose to intentionally increase this albedo by methods that include:

- Stratospheric sulphate aerosols – the intentional addition of sulphate aerosols into the stratosphere.
- Space-based reflectors – the placement of mirrors into space (distances in various

many CDR techniques is a limitation. With the exception of afforestation, the Royal Society (2009) evaluated CDR approaches as having 'very poor' to 'poor' affordability.

proposals range from near-Earth orbits to 1.5 million kilometers from the Earth).

- Cloud whitening – the intentional addition of cloud-condensation nuclei, through spraying salt water into the atmosphere over parts of the ocean, to increase clouds' albedo and lifetime.
- Surface albedo change – the intentional increase of the albedo of the Earth's surface to reflect sunlight. Proposals have included more reflective crop and grasslands varieties, and desert reflectors (Royal Society, 2009).

This thesis will deal almost exclusively with stratospheric sulphate aerosols. Full technical descriptions of the other SRM options may be found in the Royal Society's 2009 report entitled: *Geoengineering the Climate: Science, Governance and Uncertainty*.

2.3.1 The mechanics and efficacy of cooling the climate

Sulphate aerosol injection is the SRM strategy that has received the most attention and debate in the scientific and policy literature. Sulphate aerosols, no matter where in the atmosphere, scatter sunlight in all directions, including a percentage into space. Just a few grams of aerosols placed in the stratosphere can scatter enough sunlight to offset the warming of a tonne of atmospheric CO_2 (Keith *et al.*, 2010; Parson, 2010).[7] It is proposed that by continually injecting sulphate precursors like sulphuric acid (H_2SO_4) or sulphur dioxide (SO_2) into the stratosphere, it should be possible to reduce insolation sufficiently to cool the planet (Crutzen, 2006; Rasch *et al.*, 2008b; Pierce *et al.*, 2010). Offsetting a doubling of CO_2 (which has a radiative forcing of + 4 W/m^2) requires an estimated decrease in insolation by about 1.8% (Bala *et al.*, 2000).

[7] Sulphate aerosols cause a negative forcing regardless of their location in the atmosphere, and currently contribute to a globally averaged radiative forcing of -0.4 ± 0.2 W/m^2 (IPCC, 2007b)

Volcanoes have an important cooling influence on the climate because they emit sulphate aerosol precursors into the atmosphere during eruption. The eruption of Mount Pinatubo in 1991, for example, injected twenty megatons of sulphate aerosols into the stratosphere, resulting in a global cooling of 0.5°C (Lacis *et al.*, 1995; Robock, 2002). This cooling effect was quick and observed within months (Robock, 2002). This strong, but short-term negative forcing lasted for about two years, after which the sulphate aerosols coagulated and settled out of the stratosphere (Robock, 2002; Rasch *et al.*, 2008b). To recreate this process intentionally, as per SRM proposals, a continuous layer of sulphates must be created and maintained over the required period of cooling.

2.3.2 The efficacy of SRM

SRM is often described as a temperature intervention with potential precipitation impacts. A more precise description, however, is an intentionally introduced negative radiative forcing that leads to a climatic response, including changes in temperature and precipitation. These changes are important for considering the efficacy of SRM. There have been no peer-reviewed field experiments of any form of sulphate aerosols,[8] so all available data concerning its potential are derived from basic physics, extrapolations of volcanic activity, and climate modelling experiments.

Climatic responses to changes in insolation and GHGs are driven by different physical mechanisms, and result in different temperature and precipitation regimes. Modelling tests suggest that offsetting a radiative forcing caused by a doubling of CO_2 would compensate for the

[8] There was a funded project in United Kingdom called the Stratospheric Particle Injection for Climate Engineering (SPICE) that proposed building and assessing the feasibility of a hose suspended by a tethered balloon as a means of stratospheric droplet distribution. The outdoor test was not designed to study any climatic response, rather a specific delivery method. The field test was cancelled in 2012 due to concerns over intellectual property and inadequate public engagement.

associated global average temperature increase but be accompanied by lower global precipitation levels (Bala and Caldeira, 2000; Caldeira and Matthews, 2007; Bala *et al.*, 2008; Caldeira and Wood, 2008; Rasch *et al.*, 2008b; Heckendorn *et al.*, 2009; Robock *et al.*, 2009; Ricke *et al.*, 2010). The trade-off is such that SRM could be used to compensate for either temperature or precipitation, but not both.[9] The magnitude of this trade-off was examined by Calderia and Wood (2008). They found, in a high-carbon world (doubling of CO_2) with no SRM, there was a significant increase in global precipitation. Comparatively, an SRM-controlled world experienced less precipitation then the current regime, but significant deviations were observed over only 4% of the Earth's surface. The conclusion from this study suggests that precipitation in an SRM-managed world would not perfectly match current precipitation levels, but there would be significantly less change than in the high-carbon environment.

Understanding global trends provide a generalized view of SRM's potential efficacy. Regional changes in temperature and precipitation are of vital importance when considering economic and social impacts of SRM. Similar to climate change, the use of SRM will result in variations in climate responses at the regional level, creating unequal benefits and risks (Caldeira and Wood, 2008; Rasch *et al.*, 2008a; Robock *et al.*, 2008; Ricke *et al.*, 2010). Modelling at the regional scale is more uncertain than global trends, but broadly, stabilizing global temperatures would produce overcooling near the Equator, and residual warming near the poles (Caldeira and Wood, 2008). However, average regional temperature and precipitation change and variation are both smaller in an SRM-managed world than in a high-carbon world (Moreno-Cruz *et al.*, 2011). These two climatic responses vary across regions such that Moreno-Cruz *et al.* (2011: 12)

[9] In a geoengineered world, lower precipitation rates occur because the solar forcing is more effective at driving global mean evaporation than a CO_2 forcing of a comparable magnitude (Bala *et al.*, 2008).

suggest, "a globally optimal level of SRM can compensate for a large proportion of damages at a regional level." This level was set at a threshold that minimizes damage to all regions and ensures no one is worse-off. Research into regional responses is an important area of continued research.

The key points from this discussion on efficacy for this thesis are:

- SRM could exert powerful leverage over controlling aspects of our climate, but defining its societal roles and technical objectives is essential for characterizing its impacts;
- Physical limitations of the climate suggest that we can offset a temperature change or a precipitation change, but not both; and
- Regional effectiveness is variable.

2.3.3 Engineering a reflective layer

Ideally, long-term cooling would be achieved through a negative forcing maintained over a long period of time, using as little sulphates as possible. Three factors are important to consider when engineering such a layer: A) particle size; B) location of the layer; and C) distribution of the particles.

A) Particle size

An optimal sulphate particle must be about 0.1 μm in diameter to ensure effective backscattering, and have the ability to remain aloft for a maximal duration (Rasch *et al.*, 2008b; Pierce *et al.*, 2010). Maintaining this size is an engineering challenge as injected sulphur compounds tend to coagulate into larger less effective particles (Rasch *et al.*, 2008b; Keith, 2010; Pierce *et al.*, 2010). Depending on particle size, a sulphate aerosol regime could likely be achieved with 1.5 to 5 Teragrams of injected sulphur per year (Tg S/yr) (Rasch *et al.*, 2008b). For comparison about 55 Tg S was emitted globally in 2000 from burning fossil fuel (Stern,

2005).

B) Location of the layer

The majority of SRM proposals rely on the stability of the stratosphere to ensure extended lifetimes of the aerosols. It does not experience the same vertical mixing as the troposphere[10] and as such the aerosols remain aloft for up to two years, rather than the five-day average in the troposphere (Houghton, 2009).[11]

C) Distribution of the particles

Stratospheric circulation results in the poleward distribution of aerosols in the atmosphere, such that aerosols from the Tropics migrate to the middle and high latitudes. Thus delivering material into the stratosphere above the Tropics would result in the most evenly distributed and longest lasting sulphate layer (Robock *et al.*, 2008; Pierce *et al.*, 2010).

There are many proposed methods to introduce sulphates into the stratosphere, ranging from missiles to airplanes. In an engineering cost analysis of the different delivery systems, it was concluded that the basic technological capacity to inject 1-5 Tg of materials into the stratosphere exists today using several methods for less than $8 billion a year (McClellan *et al.*, 2012). Of the techniques analyzed, the most competitive were modified airplanes designed specifically for stratospheric flight, or airships (McClellan *et al.*, 2012). To provide a frame of reference, McClellan *et al.* (2012: 6) state, "Airplane geoengineering operations would be comparable to the yearly operations of a small airline, and are dwarfed by the operations of a

[10] The troposphere is the lower atmosphere that extends from the Earth's surface up to on average 17 kilometers above the surface (about 7 km at the Poles and 20 km at the Equator).

[11] The stratosphere has an inverted temperature profile to the troposphere, meaning temperature increases as you travel up through the stratosphere. Warm air is less dense than colder air, and rises and falls based on its density. In the troposphere, cooler, denser air sits over warmer, less dense air, meaning air parcels will rise, creating vertical mixing in this layer. This mixing moves the sulphates around and promotes coagulation creating short lifetimes. The stratosphere is stable because warmer, less dense air sits over cooler, denser air, thus little vertical mixing. This stability allows for the long residence times for sulphates and other compounds.

large airline like FedEx or Southwest." This cost is very small in comparison to the 1% of world GDP per annum (roughly $700 billion/year) estimated to mitigate to an atmospheric carbon concentration of 550 ppm (Stern, 2007).

The conclusion that can be drawn from engineering considerations is: 1) the creation and cost of an SRM layer is not a real limiting factor for SRM; and 2) it is a cheap intervention with respect to the leverage it allows over the climate (NAS, 1992; Schelling, 1996; Keith, 2000; Keith, 2001; Barrett, 2008)

2.3.4 Impacts of SRM

The addition of stratospheric sulphates is likely to produce a set of intervention-related impacts. The following discussion considers five of these impacts: A) ozone depletion; B) changes in light diffusion; C) termination effects; D) health impacts; and E) as yet unknown impacts.

A) Ozone depletion

The introduction of more sulphate aerosols will slow the recovery of stratospheric ozone (Crutzen, 2006; Tilmes *et al.*, 2008; Heckendorn *et al.*, 2009). Specifically 2 Tg S/ yr would slow the recovery by about 30 years for the Antarctic ozone hole and cause up to a twofold increase in chemical ozone depletion in the Northern Hemisphere (Tilmes *et al.*, 2009). Stratospheric sulphates enhance chlorine-induced ozone destruction, and as such, SRM-related ozone destruction is in part dependent on the atmospheric chlorine concentrations (Heckendorn *et al.*, 2009), which are in decline (NOAA, 2013).

B) Changes in light diffusion

Atmospheric aerosols would increase the ratio of diffuse-to-direct light. Sulphate aerosols scatter light in all directions, therefore sunlight reaching the surface in a geoengineered

world would be increasingly diffuse. An increased ratio of diffuse-to-direct light will cause a whitening of the daytime sky (Keith, 2010) and a likely increase in primary plant productivity (Gu *et al.*, 2002; Gu *et al.*, 2003; Farquhar *et al.*, 2003).

C) Termination Effect

If SRM were to be stopped and the atmospheric carbon concentration did not correspond to the global temperature, there would be a rapid global temperature increase. This is a result of masking the CO_2 forcing but not removing it. Called the "termination effect," this rapid temperature rise would continue until an equilibrium was reached with the CO_2 forcing (Matthews and Caldeira, 2007). Without the negative forcing, rate of temperature change could be as high as 4^oC per decade, 20 times faster than current rates of climate change (Matthews and Caldeira, 2007). This rapid change would likely have much more serious impacts than the same magnitude of warming that took place gradually. While it is technically possible to stop SRM at any time (by stopping the injection of sulphates), it could really only be done once the carbon forcing was low enough to cause no warming when the aerosols were removed.

D) Health Effects

Globally, it is estimated that tropospheric sulphate aerosols cause about 0.8 million deaths per year (WHO, 2001). Research is currently underway to quantify the additional deaths that might be attributed to an SRM stratospheric regime. At the time of this publication, there are no published figures. While SRM would contribute to loss of human life, the total mass of the aerosols that would be used is relatively small compared to our current tropospheric sulphate emissions and thus additional loss of life would likely be smaller than current rates.

E) Unknown Impacts

As with any technology, there is certainly the possibility that a large-scale deployment of SRM may cause impacts that we are unable to predict – these are the so-called "unknown unknowns." The concern with SRM is the global scale and extent of these unknown impacts.

2.3.5 Unaddressed Climate Impacts

CO_2 does not just change the global energy balance, it also has important chemical impacts on the oceans. The ocean absorbs CO_2 in equilibrium with the atmospheric concentration. This absorption leads to the creation and dissociation of carbonic acid, ultimately decreasing the ocean's pH. As the atmospheric concentration increases, so too does this uptake, resulting in ocean acidification (IPCC, 2007b). The increased acidity of the waters will have detrimental effects on marine ecosystems. As sulphate aerosols do not change atmospheric carbon concentrations (and indeed allow for their potential increase), this impact of CO_2 is left unaddressed by SRM (Matthews *et al.*, 2009).

2.3.6 Social and political concerns of SRM

Social and political factors are likely to be central to discussions over the acceptability and future of any SRM strategy (Royal Society, 2009). Described here are some of the major social and political concerns that are regularly brought up in the literature.

1) The existence of SRM might cause people to mitigate less because SRM is cheap and easy, while mitigation is not (Keith, 2000; Schneider, 2001; Corner and Pidgeon, 2010).
2) SRM presents major governance challenges, both at the research stage and more broadly, should deployment ever occur (Schneider, 2001). Managing the control and coordination of national and international groups requires thoughtful and potentially novel governance mechanisms (Royal Society, 2009). In the event of deployment, long-term stability of the

control and coordination of sulphate injections is required to ensure that the layer is maintained.

3) SRM could potentially be used as a weapon to cause climate and weather changes in an enemy nation (Keith and Dowlatabadi, 1992; NAS, 1992).[12]

4) The low cost of SRM makes it feasible for a small group of nations or very wealthy individuals to act unilaterally (Barrett, 2008). This is unlike mitigation, which requires major international cooperation to be effective in the long-term. There are international relations and stability concerns given the potential for unilateral deployment of SRM in a nuclearized world. Depending on the nations involved, and the extent of any impacts from SRM, these decisions may introduce considerable international tension (Schneider, 2001).

2.3.7 The novelty of SRM

SRM is a unique technology to study because it is novel in a way many new technologies are not. The true novelty of SRM lies neither in the advancement of scientific understanding of atmospheric sulphate aerosols nor the technical design of an SRM machine, rather it relates to how SRM changes the relationship between humans and nature. SRM forces a shift of our human role from passive and unintentional agents of climate change, to intentional and active climate mangers. At its core, this represents a conflict between two opposing worldviews: "anthropocentric expansion" and "stewardship" (Schneider, 2001). Moving towards anthropocentric expansion presents a redefined human relationship with the planet and as such

[12] There is an international United Nations treaty called: Environmental Modification Convention (ENMOD) banning the use of weather modification as a weapon. This treaty may limit the weaponization of SRM.

novel social, political and ethical questions. It is through understanding these criteria that we can explore the acceptability of SRM.

2.4 Chapter summary

This chapter outlined the emerging CDR and SRM geoengineering options. The important conclusions to consider before transitioning into an exploration of SRM opinions are as follows:

1) A reduction in global atmospheric carbon concentrations is the only *permanent* method to limit climate change. Mitigation and CDR are expensive and they are slow to change the climate.
2) SRM may be used to quickly and cheaply – but imperfectly – countervail the temperature or precipitation changes caused by increased radiative forcing.
3) SRM may be the only near-term intervention that can manage the risk of the latent long-term forcing caused by current concentrations of atmospheric carbon.
4) SRM will likely impact the environment in a set of known and potentially unknown ways.
5) SRM is a global intervention, and due to its low cost does not necessarily require global cooperation to use.
6) Creating an ideal stratospheric aerosol layer presents some engineering challenges (e.g. coagulation rates and injection regimes), but assessments suggest that the technology exists to undertake this action.

CHAPTER 3: TECHNOLOGICAL ACCEPTABILITY AND JUDGMENTS OF SRM

3.1 Introduction

The previous chapter introduces the importance of social issues when considering SRM, highlighting some ethical, management, governance and security challenges. As Corner *et al.* (2013: 3) comment, "…as with other emerging technologies before them, geoengineering proposals are likely to act as a catalyst for wider societal debates that reflect much more than simply an evaluation of the physical risks or benefits a particular technology may pose." This thesis contributes to the growing body of literature exploring this wider societal debate. To examine the current opinions and judgments of SRM, we must review what is already understood about the factors that influence acceptability perceptions of technology more generally.

In the first section of this chapter, I explore the framing of SRM's technological development. This is followed by the definition of technological acceptability. After clarifying the definition, I provide a summary of the relevant literature grounding the empirical work presented in this thesis. To do so, I review three dimensions that influence perceptions of technological acceptability. Finally, I provide a brief overview of the methodological issues involved in the exploration of judgments of new technologies like SRM. It should be noted that some further background, specifically relevant to the individual studies, can be found at the beginning of each of Chapters 4 and 5.

3.2 Stratospheric aerosols as a technology

Prior to a discussion of technological acceptability, the classification of stratospheric aerosols technical development merits a deeper analysis. At the time of this publication, SRM is little more than a technical idea that is modeled after a natural analog (volcanoes), which is likely

to be accomplished with little technical innovation. When sulphate aerosols are described in the literature, it is often as a stylized reflective layer in the stratosphere, not a defined product designed to cool the planet. This is largely because there is no 'intentional stratospheric aerosol machine' that can be held up as the archetypal technology. The basic components to undertake an SRM injection regime likely exists today with little need for development (see section 2.3.3). So in a limited sense, the technical capacity exists. Considering the lack of a broader technical system required to support this technique including monitoring, regulatory and commercial structures, one can surmise that SRM is very early in its development.

Grappling with defining its current state of development, scholars have described sulphate aerosols systems using three different terms: technological imaginary, an emerging technology and an upstream technology. The first label, technological imaginary, is defined as an assemblage of implicit assumptions, values and visions of a future technology (Rayner, 2012; Jasanoff *et al.*, 2013; Markusson, 2013). These imaginaries define what could be, how a technology may develop, and how it could be used – thus constituting the understanding of the technology without a physical artefact. The second term, emerging technology, encompasses three specific features: 1) rapid growth of the knowledge base; 2) a transition or change to something new; and 3) a potential area (frequently defined as market or economic) that is not already exploited (Cozzens *et al.*, 2005). The final term, upstream technology, can be used, "if significant research and development has yet to commence, risks and benefits are highly uncertain, and entrenched attitudes or social representations have yet to be established" (Pidgeon *et al.*, 2012: 4177). All of these terms suggest slightly different characteristics but for this dissertation, a precise label is not necessary. Rather, the following broader characteristics are useful:

- Sulphate aerosols systems are in the early stages of development;
- Its features are being constituted by research, visions and values of relevant stakeholders; and
- The social representations of the technology are in the process of forming with no one specific representation entrenched.

3.3 Acceptance and acceptability: definitions

Given SRM is a technology early in its development, studying people's opinions and attitudes towards it provides valuable insights for its design, public engagement, communication processes, and the future role in society (Huijts *et al.*, 2012). Consider the following two concepts: technological acceptance and acceptability. Technological acceptance refers to a pattern of observable behaviours that demonstrate that individuals are enabling or promoting the use of a technology (Huijts *et al.*, 2012). This could include actively promoting, buying and/or using a technology. Technological acceptability, however, is an evaluative judgment which "gauges whether the technology or technological method at issue conforms with societal values and norms sufficiently well to be placed on the table as a viable alternative to other technologies" (Wolfe *et al.*, 2001: 137). Thus, it is a set of attitudes developed through perceptions about the technology, its implementation, our affective response and our broader social and cultural beliefs (Huijts *et al.*, 2012). Technological acceptability should be considered on a spectrum, with one extreme, complete acceptability, a judgment that a technology conforms in all cases to values, and norms and at the other extreme, complete unacceptability, a judgment that a technology is intolerable as it violates fundamental values and norms (Wolfe *et al.*, 2001). Conditional acceptability is a middle ground where certain applications of a technology may be perceived as acceptable given certain conditions.

As an aside, the concept of acceptability as it relates to SRM, is *not* intended to reflect any position about the end-use or deployment of SRM. Instead, it is a convenient construct to explore emerging judgments of SRM. By describing dimensions of acceptability, I am not implying that acceptance should be SRM's ultimate end, indeed one plausible response is its outright societal rejection. My research is designed to provide information on how individuals, varied as they are, perceive and think about SRM, as a means to understand the dimensions and challenges it engenders.

3.4 Factors influencing perceptions of a technology's acceptability

There is a broad body of literature on the acceptability of risk. It has evolved from the early work of researchers like Starr (1969), who observed people were more likely to accept voluntarily-chosen risks, to current day explorations of technological acceptability of emerging technologies (Lee *et al.*, 2005; Kahan *et al.*, 2009; Pidgeon *et al.*, 2009; Binder *et al.*, 2012). By way of summarizing this literature, and expanding on a framework by Wolfe *et al.* (2001), I propose technological acceptability may be explored in three dimensions: technology-specific, implementation and contextual. The descriptions of each dimension is as follows:

1) *Technology-specific dimension* - This is a direct evaluation of the specific technology. Factors contributing to this dimension include judgments and perceptions about cost-benefit trade-offs, perceptions of risk, framing of specific technical information, and perceptions of relevant trade-offs with other technologies that are operating in the same space.
2) *Implementation dimension* – This is the perception of how a technology is or could be implemented. Important factors here are perceptions of trust in information providers and actors engaged with the technology (e.g. researchers, operators, government

regulators), procedural fairness and distributive fairness.

3) *Contextual dimension* – This dimension describes the setting or context in which the technology may be considered. This includes the current and historical circumstances of the technology in question, as well as, other related and/or similar technologies. It also includes the broader cultural values and attitudes of individuals and groups.

The following is a description of important factors influencing each dimension, which are relevant to the study of SRM.

3.4.1 Technology-specific dimension

Technology-specific criteria focus on specific technical understanding, as such perceptions of risks, benefits and affective responses to the technology are important. Negative risk perceptions, defined as intuitive judgments of risk, are associated with opposition to a technology (Slovic, 1987). They are fast, automatic, effortless and governed by habit and emotional response (Kahneman, 2003; Slovic *et al.*, 2004). Qualitative characteristics rather than quantitative measures (e.g. fatality estimation from risk assessments), are more salient in these judgments (Slovic, 1987; Slovic, 2001). Specifically, characteristics including: controllability, extent of impact, voluntariness, equitability of impacts, catastrophic potential, novelty of the risk, extent of scientific understanding and extent to which the hazard can be perceived as natural, are important in our risk perceptions (Fischhoff *et al.*, 1978a; Slovic *et al.*, 1980; Slovic, 1987). A negative risk perception is likely when a technology is perceived as involuntary (to the individual), novel, uncontrollable (to the individual), potentially catastrophic on a global scale and intervening in nature. This last feature bears highlighting because perceptions of naturalness are emerging as a notable factor in geoengineering risk perceptions (National Environmental Research Council, 2010; Corner *et al.*, 2013).

It is not just perceptions of risk that influence judgments of acceptability. Empirical evidence from studies of other emerging technologies show that perceived benefits are also an important factor (Breakwell, 2007). Research suggests that there is an inverse relation between risk and benefit perceptions – the greater the perceived benefits, the lower the risk (Fischhoff *et al.*, 1978b; McDaniels *et al.*, 1999). For emerging products such as nanotechnology, acceptability is largely determined by perceived benefits, and to a lesser extent perceived risks (Cobb *et al.*, 2004; Pidgeon *et al.*, 2009; Satterfield *et al.*, 2009).

There is a formative influence of emotions on intuitive judgments (Slovic, 1999; Finucane *et al.*, 2000; Slovic *et al.*, 2004). Objects or ideas evoke unconscious emotional responses that are labeled with feelings of "goodness" or "badness." Negative emotions like anger, sadness and fear contribute to negative affect, which results in judgments of higher risk and lower benefits (Finucane *et al.*, 2000). More specifically, when an outcome carries a salient and strong affective meaning (e.g. a nuclear reactor core melt-down), individuals focus on the possibility of this specific outcome, disregarding probabilistic data (Loewenstein *et al.*, 2001). This 'all or nothing' attitude concerning extreme events is likely to be important for SRM given the extent and scale of its risks.

3.4.2 Implementation dimension

Concerning a technology's implementation, criteria of acceptability are likely to focus on the implementation process such as constructs like trust and fairness. As a technology increases in complexity, it becomes more challenging to understand for lay people. One way an individual deals with their lack of knowledge is to trust more knowledgeable people (e.g. researchers) or institutions (e.g. governments) (Earle *et al.*, 1995; Siegrist *et al.*, 2000; Gaskell *et al.*, 2005). This trust spans three strata – public trust, institutional trust and specific trust (Breakwell, 2007).

Public trust speaks to the broad system that makes decisions, institutional trust is an overall trust in an organization over time and specific trust refers to trust of an organization undertaking a specific task. Taken as a whole, this is referred to as social trust. High levels of social trust are associated with perceptions of greater benefit and lesser risk for emerging technologies such as gene-recombinant technology (Siegrist, 2000; Tanaka, 2004) and nanotechnology (Siegrist *et al.*, 2007). Trust is founded upon the perception of shared values (Earle and Cvetkovich, 1995) and includes elements of commitment, competency, caring and predictability (Frewer *et al.*, 1996). With SRM, where currently there are no operators or regulatory agencies, the role of trust in information providers is a central question to consider.

A second important facet of the implementation dimension relates to perceptions of fairness. At the most basic level, people are more willing to accept the outcome of a decision process they perceived is fair, (Besley, 2010). Fairness is the perception that the result of a decision is equitable (Lind *et al.*, 1990). Often fairness is categorized into the following three groupings: distributive fairness, procedural fairness and interpersonal fairness. Distributive fairness describes perceptions of a decision as equitable or needed. Procedural fairness refers to the decision process emphasizing an individual's perception of inclusion. Finally, interpersonal fairness deals with perceptions of the decision-makers themselves as trustworthy and respectful agents (Besley *et al.*, 2005; Besley, 2010). Research by McComas *et al*., (2008) suggest that negative perceptions of distributive justice, in particular, were predictors for concern about emerging technologies including nanotechnology, agricultural biotechnology, and gene therapy. Issues of fairness, specifically procedural and distributive, are central to climate change discussions (IPCC, 2001) and likely very relevant for SRM.

3.4.3 Contextual dimension

The contextual dimension describes the broader circumstances in which the technology is considered. Judgments are influenced by the values individuals hold. Specific cultural views act as priors in our decision-making, influencing the entire cognition process. Specific views have been used to explain the polarization of factual disagreement observed on certain topics like global warming across distinct social groups (Kahan *et al.*, 2006). Attitudes towards technology more generally have been shown to be very important in judgments of emerging technologies. For example, studies have shown an overall positive perception of nanotechnology is likely rooted in an overall positive view of science as a whole (Cobb and Macoubrie, 2004). In a meta-analysis of nanotechnology opinion surveys, studies consistently showed participants perceived higher benefits than risks, despite the factors that contribute to negative risk perceptions (new, unknown to science, unobservable) (Satterfield 2009). Low "techno-skepticism" of nanotechnology was also observed in multi-day deliberative democracy exercises where participants "demonstrated almost complete acceptance of the likelihood of scientific promises being realized at a technical level" (Pidgeon *et al.*, 2009: 95). Perceptions of SRM are likely to be more favourable in populations that exhibit higher technological optimism.

With technological development comes a range of uncertainties related to social changes, relationship and institutions. As such, new technologies can become a node for broader social issues including control, trust, influence and knowledge limitation (Kearnes *et al.*, 2006). Acceptability is easily influenced by controversy over the specific technology or over technologies that are perceived as being similar (Pidgeon *et al.*, 2012). Therefore, controversies concerning other geoengineering technologies, similar to that of 2012 when a small group was found covertly dumping iron in the Canadian Pacific to test ocean fertilization schemes (CBC,

Oct 16, 2012), will influence the discussion and perceptions of sulphate aerosols. As well, other environmental issues perceived as similar to SRM are likely to influence technical judgments. Pidgeon *et al.* (2012) posits one such issue is air pollution, which has longstanding negative associations. Finally, geoengineering will be considered as part of the larger climate change context. This issue has become a very polarized social and political issue. Continuing climate controversies will likely influence the acceptability of SRM.

3.4.4 Potential SRM judgments

Considering the three dimensions of acceptability, it is likely that qualitative characteristics of SRM (e.g. involuntary, novel, uncontrollable - to the individual, potentially catastrophic and unnatural) will strongly contribute to higher risk perceptions. However, mitigating factors such as trust in researchers may mean specific areas such as SRM research are judged more favourably. Technological optimism and high perceptions of benefits may also positively influence acceptability of SRM (analogous to observations in opinions of nanotechnology). Broader social issues like shifting patterns of control, trust and influence of agencies, hubristic claims of technology and limits of knowledge (Kearnes *et al.*, 2006) are likely to be important factors in how SRM is perceived. This thesis, grounded in these dimensions, will evaluate criteria that are potentially influencing acceptability perception of SRM.

3.5 Methodological challenges of researching new technologies

Prior to the presentation of the empirical research, it is important to address a methodological concern with studying areas of low familiarity. Early or newly formed opinions are often labile and easily affected by heuristics (short-cuts in intuitive judgments) and issue framing (Lee *et al.*, 2005). Methodologically, this presents two specific challenges: long-term stability of opinions and preference construction. The latter is further explained below.

Methodologically, when eliciting opinions in a survey, one would like to capture a subject's 'true' thoughts. The cognitive process of answering a question is as follows: "a subject must (a) interpret the question, (b) generalize an opinion, (c) access relevant information, (d) decide how to use that information, (e) compute the judgment, (f) format a response, and (g) edit the response" (Sudman *et al.*, 1995: 58). In situations that are novel or unfamiliar, people often do not have readily accessible information to formulate their response. Instead, they draw on past experience, implications or clues from the researcher, and opinions of closely related topics, to build their responses (Slovic, 1995; Payne *et al.*, 1999). In such cases, the researcher is sampling preferences that are strongly contingent on how the issue is framed and an individual's cognitive limitations (Irwin *et al.*, 1993; Slovic, 1995). This is referred to as constructed preference. In our examinations of SRM opinions, people unfamiliar with SRM are very likely to be constructing their preferences. Thoughtful survey processes have been known to reduce this biasing effect (but not necessarily eliminate it) (Slovic, 1995). The survey tools in this dissertation were designed cognizant of the following guidelines:

- Information is transparent and proportional to the importance of the question;
- Questions are sensitive to the manipulation it is intended to measure, but insensitive to the way the topic is framed;
- A full range of available options, objectives and important values are provided to be considered by the subjects (Payne *et al.*, 1999).

3.6 Conclusion

Opinions of stratospheric sulphate aerosols are important for understanding how the technology may be constituted in society. This will affect the decisions we make in the future concerning all geoengineering and more broadly other climate approaches. This chapter

presented three dimensions of technological acceptability that will directly influence these perceptions. Chapter 4 will provide empirical data on aspects of these dimensions. Chapter 5 will provide some of the first empirical evidence exploring trade-off decisions of experts more familiar with this technology.

CHAPTER 4: LAY JUDGMENTS OF SRM

4.1 Introduction

> Are everyday citizens around the world ready and able to discuss SRM in a meaningful way? We think the answer is yes. The potential for diverse publics to meaningfully engage in early dialogue about emergent technologies has been amply demonstrated over the past decade. In cases ranging from genetically modified foods to nanotechnology, researchers have found that citizens are able to engage in thoughtful discussion about nascent and complex technologies even when public awareness is low (Kearnes *et al.*, 2006; Stilgoe *et al.*, 2007). In fact, public engagement can be more effective when initiated while technologies and the public discourses surrounding them are still taking shape. Participants in public engagement exercises do not need to have substantial knowledge of the technology of interest beforehand. They can come to well-reasoned judgments about a technology through a combination of basic information conveyed during the engagement process, their own 'lay' knowledge about nature and technology, and their commonsense knowledge of the social world (Marris *et al.*, 2001). (Carr *et al.*, 2013: 6)

This quote, from a *Climatic Change* opinion piece (which I was a co-author) serves as a concise statement of my motivations for the empirical research that follows and captures the value of lay knowledge.

The first portion of this chapter will present research conducted in the fall of 2010, examining emerging familiarity and perceptions of SRM. At the time of the research, very little was known about the state of lay people's awareness or their opinions. The first section of this chapter, reprints (in its entirety) my publication from *Environmental Research Letters*. After the article, I revisit a set of findings in light of newly published data. The second part of this chapter presents further findings from the survey research, which describes the non-scientific tensions participants raised in response to its final open-ended question. This analysis is based on a chapter I co-authored in *Engineering the Climate: The Ethics of Solar Radiation Management*. The final section of this chapter summarizes the current body of literature on lay judgments of SRM and the growing understanding of SRM acceptability.

This chapter includes text from three publications I have co-authored. These papers each contribute to the discussion on the public's role and their current judgments of SRM. My contribution to each paper are as follows:

1. **Mercer, A.**, D. Keith & J. Sharp (2011). "Public understanding of Solar Radiation Management." *Environmental Research Letters*. 6:4 044006 DOI:10.1088/1748-9326/6/4/044006
    - I was the main author of this publication. I designed and managed the survey research. I was responsible for the primary data analysis, and the discussion of the results. I was the primary author of the manuscript. The co-authors advised and reviewed at each stage of the research.
    - This paper was chosen by the editorial staff at *Environmental Research Letters* as a 2011 Highlight Paper.
2. Carr, W., **A. Mercer** & C. Palmer (2012). "Public concerns about the ethics of SRM." *Engineering the Climate: The Ethics of Solar Radiation Management*. Lexington Books: Maryland.
    - As the second author of this publication, I was responsible for data collection. I worked jointly with Wylie Carr on the analysis. The manuscript was a collaboration between the three authors.
3. Carr, W., C. Preston, L. Yung, B. Szerszynski, D. Keith & **A. Mercer** (2013). "Public engagement on solar radiation management and why it needs to happen now." *Climatic Change*. 121(3), 567-77, DOI: 10.1007/s10584-013-0763-y
    - As a co-author of this publication, I was responsible for early discussions of the opinion piece and a section of the manuscript.

4.2 Public understanding of solar radiation management

This section is a reprint of the published paper:

Mercer, Ashley, D. Keith & J. Sharp (2011). "Public understanding of Solar Radiation Management." *Environmental Research Letters*. 6:4 044006. DOI:10.1088/1748-9326/6/4/044006.

4.2.1 Abstract

We report the results of the first large-scale international survey of public perception of geoengineering and solar radiation management (SRM). Our sample of 3,105 individuals in the United States, Canada and the United Kingdom was recruited by survey firms that administer internet surveys to nationally representative population samples. Measured familiarity was higher than expected, with 8% and 45% of the population correctly defining the terms *geoengineering* and *climate engineering* respectively. There was strong support for allowing the study of SRM. Support decreased and uncertainty rose as subjects were asked about their support for using SRM immediately, or to stop a climate emergency. Support for SRM is generally associated with environmental views and optimism about scientific research while opposition is associated with conservative political views and distrust of government; however analysis of *supporters* and *detractors* suggests that there are distinct sub-groups within each. The potential risks of SRM are important drivers of public perception with the most salient being damages to the ozone layer and unknown risks. SRM is a new technology and public opinions are just forming, thus all reported results are sensitive to changes in framing, future information on risks and benefits, and changes to context.

4.2.2 Introduction

Until recently, scientific, political and public discourse on responses to climate change has centered on two fundamental response options: mitigation (reducing emissions) and adaptation. Deliberate large-scale engineering to reduce or offset climate change driven by greenhouse gas emissions represents a third class of options (Royal Society, 2009). Known as *geoengineering* or *climate engineering*, this third response comprises a broad array of techniques that can be broadly divided into two very different approaches: carbon dioxide removal and solar

radiation management (SRM). Most SRM techniques act by increasing the albedo of the atmosphere through methods such as the injection of sulphate aerosols into the stratosphere where they would reflect some solar energy back to space lowering the global temperature. Compared to other response options SRM is inexpensive (NAS, 1992; Barrett, 2008; Blackstock *et al.*, 2009; Royal Society, 2009; McClellan *et al.*, 2012) and fast-acting (Caldeira and Matthews, 2007; Robock *et al.*, 2008) but it can—at best—only partially offset the impacts of increased CO_2 and caries novel environmental and social risks (Robock, 2008; Blackstock *et al.*, 2009; Corner and Pidgeon, 2010; Keith *et al.*, 2010). Risks include: changes in precipitation (Ricke *et al.*, 2010), a slowing recovery of the ozone layer (Crutzen, 2006; Tilmes *et al.*, 2008), and reductions in political and personal motivations to decarbonise the economy (Keith, 2000). SRM constitutes a global intervention, with both benefits and risks being felt at this scale.

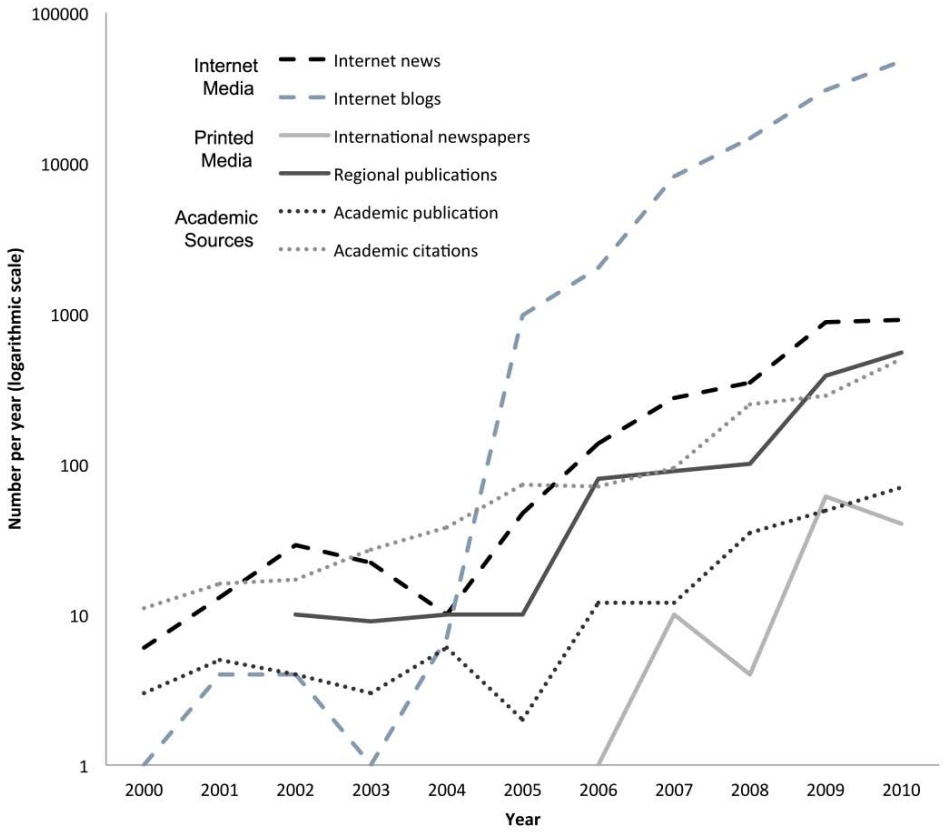
Discussion of SRM within the scientific literature dates back to the 1960s. While major climate change assessment reports of the 1970s and 1980s discussed its possible use as part of a broadly inclusive framing of climate change, it was largely ignored as concerns about anthropogenic climate change gained political visibility (Keith, 2000). While sporadic articles were published over the past few decades, discussion of SRM remained on the periphery of the climate debate and shrouded in taboo, due to a widespread concern that public discussion of SRM would lessen the incentives for political action to restrain emissions (Kiehl, 2006). The taboo was broken in 2006 when Paul Crutzen published an editorial essay urging more systematic consideration of SRM (Crutzen, 2006). We speculate that the fact that Crutzen is a Nobel Laureate for work on ozone chemistry, combined with the fact that ozone depletion is a salient risk of SRM, contributed to the influence of this paper. In any case, the paper triggered rapid growth in research and debate on SRM within academic and climate policy communities

(Figure 4.1). Recent debate on SRM has been marked by hearings in the US Congress and the UK Parliament, the creation of various expert panels, national research programs, and formal resolution by the Convention on Biological Diversity.

Despite this rapidly evolving dialogue, virtually no systematic data exists on the public's awareness and opinions of geoengineering. A common assumption by experts engaged on this issue is that the public is almost wholly unaware of SRM and thus cannot currently contribute to the debate meaningfully. Leiserowitz added a single question on geoengineering to a larger survey and found that only 3% of Americans could provide a correct description of geoengineering (Leiserowitz, 2010). The National Environment Research Council undertook a more comprehensive research initiative in the UK that included both an extended deliberative exercise with a small group of citizens and a small nonrepresentative survey, which suggested a similar lack of public understanding of SRM (National Environmental Research Council, 2010). Spence including a set of awareness and opinion questions on geoengineering into a UK study on energy and climate and found that about 7% of the sample "knew a fair amount" about geoengineering (Spence *et al.*, 2010). None of these studies has yet appeared in the journal literature.

While there is a the lack of studies directly assessing understanding and awareness of geoengineering, the increase in internet and printed media coverage (see Figure 4.1) suggests that the public is increasingly seeking and consuming information on geoengineering. International newspapers ran 115 stories on geoengineering in 2007-2010 compared with one story in the previous six years. Similar results hold for regional papers and bulletins and popular media such as *Rolling Stone* and *Popular Science*.

Figure 4.1 Growth in the number of publications about geoengineering from three media sources: internet (dashed lines), printed (solid lines) and academic (dotted line), from 2000 to 2010. Counts of internet news and blogs sites were established through date specific searches of geoengineering on Google News and Google Blogs. EBSCO newspaper source database was used to analyze major international newspaper (ex. The Washington Post, The Times (London), The Toronto Star, etc.) trends and Factiva database was used for the worldwide regional publication trends. ISI Web of Knowledge was used for Academic sources. All databases were accessed in May 2011.



Deployment of SRM may well reshape human's view of nature. Given the profound implications of this technology, leading researchers have called for public dialog (Blackstock *et al.*, 2010; Corner and Pidgeon, 2010; House of Commons - Science and Technology Committee, 2010; Keith *et al.*, 2010). As meaningful dialog is only possible if the participants have some coherent understanding of the technology, this study aims to inform debate about public perceptions of SRM by addressing two primary research questions:

1. How widespread is public knowledge of geoengineering and SRM?; and
2. How does the public perceive geoengineering and SRM?

The following sections present the survey method, the results, and a discussion of the implications of the survey findings.

4.2.3 Methods

An extensively pretested internet-based survey was completed by 3,105 participants in Canada, the United Kingdom and the United States between November 19 and December 7, 2010. The subjects completed an 18-question survey instrument, which was divided into five sections (see Appendix A):

1. Baseline knowledge assessment – Five Likert-scale and open-ended questions (question 1B and 2B) were designed to assess respondents' familiarity with geoengineering. A question assessing the respondents' support for the use of geoengineering was included here and repeated in section 4 to assess the impact of the information section.
2. Indices of global warming belief and technical optimism - Two multi-item Likert-scale questions were used to establish subjects' beliefs regarding climate change and to assess their technological optimism.

3. Technical information about SRM - Educational information on climate change processes, how SRM may be used to lower the global temperature, and potential benefits and risks were given in a short bullet-point informational section.
4. Perception of SRM – In this section, eight multi-item Likert-scale opinion questions were asked about SRM's potential use, the importance of particular risks and benefits of SRM, and the trustworthiness of various sources of information about SRM.
5. Demographics – Seven standard demographics questions were asked at the end of the survey.

The majority of the questions within the survey were asked on a four-point Likert scale with an additional option for "I am unsure." While we hypothesized that awareness of geoengineering might be higher than generally assumed by experts, we did not expect the public to have nuanced opinions on the use and impacts of these technologies. In cases such as this, where public opinion is nascent, a significant proportion of the sample can be expected to have no opinion. In order to reduce the extent to which a forced choice would generate spurious opinions, we elected to use a four-point Likert scale, in combination with an explicit "I am unsure" option. This ensured that mid-scale or neutral answers could not be selected as proxies for having no opinion.

All open-ended questions were coded into broad themes by a coder blind to the goal of the study. In addition, the open-ended definitions of *geoengineering* and *climate engineering*, Questions 1B and 2B respectively, were independently evaluated by two researchers, in order to determine the correctness of each definition and establish the sample's initial baseline awareness (intercoder reliability $\kappa = 0.91$). To be deemed correct, an answer had to demonstrate to the

researchers that the respondent reasonably understood the concept of geoengineering or climate engineering, including showing evidence of at least two of the following ideas:

- Suggest an environmental state or process was being changed intentionally;
- Related to climate change (but not the source of climate change); and/or
- Artificial or human-made.

4.2.3.1 Subjects

A representative sample of adults 18 years of age and older was recruited for this study. In the United States, the survey was distributed through the internet-based research firm Knowledge Networks, while in Canada and the United Kingdom Knowledge Networks worked with the internet-based research firm GMI to distribute the survey. Each firm used their established polling panels to recruit individual subject from a wide socio and economic background. Completion rates were: Canada 6%, UK 4% and US 66%. The discrepancies in the rates can be attributed to the two firms' differing approaches to survey recruitment and panel management. Knowledge Networks panel is composed of participants who are actively recruited using random digit dialing and address-based sampling techniques. The panel is managed to ensure high completion rates, by limiting the frequency of survey requests to each individual on the panel. Conversely, GMI uses primarily online recruiting, with some supplementation from offline methods such as print marketing and recruitment at trade shows and conferences, to maintain an opt-in volunteer panel. This type of panel is known for lower participation rates because participants are less consistent. Despite the varied recruiting methodologies (which lead to varied completion rates), both panels are maintained to ensure a diverse nationally representative sample is included in the study. The completion rates in this study are consistent with each

panel's past performance. No participant knew the subject of the survey prior to consenting to participate, introducing no selection bias.

The overall sample size was 3,105. However, 6.8% of the participants were excluded from the study because they appeared to have used external internet-based sources, such as Wikipedia, to inform themselves about the survey topic. The researchers identified distinctive words and phrases from the top websites found by internet searches for 'geoengineering' and 'solar radiation management.' Two of the researchers then independently assessed each open-ended definition of geoengineering and solar radiation management given by survey respondents, and if either researcher believed that an answer was influence by these sources then the participant's responses were removed from the study. The resulting sample size is 2,893.

4.2.3.2 Assessing bias introduced by the information section

It is conceivable that providing the technical information about SRM biased the sample's responses. The survey was designed and extensively pre-tested to convey scientific information about SRM in a neutral manner and in language accessible to the general public using methods described by Morgan *et al.* (2002). When asked to rate the clarity and neutrality of the information that was presented, 93% of the subjects thought that it was clear. To evaluate neutrality, participants were asked if the information they had read was biased: 59% thought that it was neutral, 2.3% thought that it opposed SRM and 38% thought that it was supportive of SRM. The effect of the educational section was further verified by an internal check where the question "Do you think that geoengineering should be used as a solution to global warming?" was asked both before and after the subjects were exposed to the information (Question 5 and 9 respectively). Of people who answered both questions, 60% did not change their opinion following the educational section, while 20% became more supportive of SRM and 21% less

supportive. "Unsure" responses dropped from 49 to 25%. Given this data, it seems unlikely that the information substantially biased the result.

4.2.3.3 Limitations of survey methods

Assessing opinions where public knowledge is low or incomplete is a methodological challenge. Large opinion surveys, such as this one, can be used as a form of initial assessment to observe the breadth of developing opinions. They allow opinions to be catalogued and aggregated using statistical methods to establish baseline observations that can be tracked over time (Fischhoff *et al.*, 2002). There are, however, two important limitations of using surveys on topics for which public opinion is not well formed. First, the rigid questions and answer format does not allow for nuanced responses (Fischhoff, 2000); and second, the propensity of some respondents to provide an opinion based on constructed preference, not derived opinion (Slovic, 1995). While the educational section provides some information about SRM as a basis for the informed responses section of the survey, it does not resolve the problem of constructed preferences. The results of this survey need to be tested against results from individual interviews of small group exercises.

4.2.4 Results

4.2.4.1 Basic understanding and mental models of geoengineering concepts

When asked, "Have you ever heard of geoengineering" (Question 1A) and "Have you ever heard of climate engineering?" (Question 2A), 20% and 24% of the sample respectively responded in the affirmative. An analysis of question 1B and 2B, which elicited unaided open-ended definitions of geoengineering and climate engineering, suggests that 8% of the population can correctly describe geoengineering, while 45% can accurately describe climate engineering. The ordering of questions was such that subjects were asked to define geoengineering prior to

climate engineering, since we expected that the term 'climate engineering' was more likely to suggest the correct answer to respondents. Familiarity varied little by country.

By way of producing an estimate, a minimum of 8% of the sample was able to define geoengineering, and 45% able to define climate engineering, which produces a very wide range of potential familiarity. While each definition showed an understanding that an environmental climate process was being altered through intentional human-intervention, we feel that an overall familiarity figure is likely to be in the lower part of this range. Some portion of participants correctly defining climate engineering can likely be attributed to being able to separately define climate and engineering. Conversely, correctly defining geoengineering can likely be attributed to some prior knowledge of these processes. This is a decidedly higher estimate than the 3% estimated by Leiserowitz, from survey done in fall 2008, and more in line with the 7% estimate of Spence et al. (2010) from a survey conducted winter of 2010. While these assessments slightly different, the increase over time may suggest a trend of growing familiarity within the broader public consistent with the trends shown in Figure 4.1.

Of the ~70% of subjects that did attempt to answer the open-ended questions, the term geoengineering produced a much larger variety of responses than climate engineering. Some of the correct answers were characterized by an unexpected level of complexity, showing a depth of knowledge. These answers included descriptions of certain methods ("[geoengineering] is man trying to change the weather using different methods such as changing an airplanes [sic] exhaust"), opinions ("[geoengineering is] trying to play God and manipulating weather patterns to control climate"], and facts ("[geoengineering is] reconstructing the planet by means of technological innovations to address the issue of global warming/climate change"). Those defining geoengineering incorrectly generally believed that it referred to one of the following six

broad topics shown in Table 4.1. The two most prominent definitions, environmental engineering and geotechnical engineering, refer to the manipulation or study of components of the earth. This would suggest that some subjects simply decomposed geoengineering into 'geo' and 'engineering' to derive their response.

Table 4.1 Distribution of incorrect definitions of geoengineering.

Category	% Distribution
Energy/Geothermal	5.7%
Genetic Engineering/Manipulation	6.2%
Other	8.3%
Engineering (unspecified)	8.8%
Geography	11.2%
Environmental engineering	17.1%
Geotechnical engineering	42.6%

In contrast, a much higher portion of the sample could correctly define climate engineering. The incorrect answers for this term were rarely wrong definitions, but rather showed insufficient evidence of understanding to meet the coding criteria. Within the correct answers, there was a high rate of describing weather modification techniques and cloud seeding. 34% of correct answers were related to manipulating weather processes and 6% of the correct responses directly used the term 'cloud seeding'.

4.2.4.2 Opinions on geoengineering

When asked if geoengineering should be used as a solution to global warming (Q9), the mean response was 2.35 with a standard deviation of 0.86 on a four-point scale where 1 = strongly disagree and 4 = strongly agree, while 25% of respondents selected "unsure" and did not mark the four-point scale. Hereafter we will report the results of similarly formatted questions using the format "Q9: M = 2.35, SD = 0.86, 25% unsure".

The following questions explored subjects' support for studying or using SRM in specific circumstances. There was high support for allowing scientists to study SRM (Q10: M = 3.08, SD = 0.804, 13% unsure). Support progressively fell and the percentage of unsure responses rose as subjects were asked about their support for using SRM to stop a climate emergency (Q11: M = 2.49, SD = 0.90, 25% unsure) and for deploying SRM immediately (Q12: M = 2.23, SD = 0.94, 25.3% unsure). When respondents were asked if SRM should never be used, no matter the situation, on average respondents disagreed (Q13: M=2.34, SD=0.10, 28% unsure). Overall the support for use of SRM is surprisingly high. Our own view, and our impression of the dominant opinion within the research and policy community, is that near term use of SRM would be reckless. The public support for SRM found here provides empirical support for oft expressed fears of a rush towards implementation.

A number of additional questions were asked in order to better understand initial opinions about SRM (summarized in Table 4.2). On average, subjects do not necessarily see SRM as a way to continue to burn fossil fuels (Q15C), and are inclined to see it as the "easy way out" (Q15D). Sixty-four percent of subjects agree that humans should not be manipulating nature in the way suggested by SRM (Q15G) and 75% of subjects agree that the earth's temperature is too complicated to fix with one technology (Q15F). Characteristic of an emerging technology, levels of uncertainty ranged across the questions. In particular, subjects are highly uncertain when asked to make specific trade-off comparisons, such as if SRM will help the planet more than it will hurt it (Q15A: unsure = 43%).

Table 4.2 Opinion elicitation based on a 4-point scale (1 = strongly disagree, 2 = somewhat disagree, 3 = somewhat agree, 4 = strongly agree).

Exact question wording	Mean	SD	Distribution (1, 2, 3, 4, Unsure)
Q15A: Solar Radiation Management will help the planet more than it will hurt it.	2.49	0.93	
Q15B: With enough research, I believe Solar Radiation Management will turn out to be safe and effective.	2.62	0.90	
Q15C: Solar Radiation Management should be used so we can continue to use oil, coal and natural gas.	2.07	0.94	
Q15D: Solar Radiation Management is the easy way out.	2.76	0.88	
Q15E: Research into Solar Radiation Management will lead to a technology that will be used no matter what the public thinks.	2.97	0.78	
Q15F: The earth's temperature is too complicated to fix with one technology.	3.34	0.71	
Q15G: Humans should not be manipulating nature in this way.	3.12	0.85	
Q15H: Solar Radiation Management is natural.	2.09	0.92	
Q15I: If scientists find that Solar Radiation Management can reduce the impacts of global warming with minimal side-effects, then I would support its use.	3.01	0.86	

4.2.4.3 Emerging opinion groups: "supporters" and "detractors"

A deeper analysis of question 9 and 13 revealed a trend that suggests the emergence of two distinct opinion groups: supporters and detractors. Supporters are defined as subjects who somewhat or strongly agreed with Q9: geoengineering should be used as a solution to global warming and somewhat or strongly disagree with Q13: SRM should never be used, no matter the situation. Conversely, detractors are defined as subjects who somewhat or strongly agreed with Q13 and somewhat or strongly disagreed with Q9. 29% of the entire sample is classified as supporters, while 20% of the sample can be classified as detractors. A comparison of means suggests these groupings are significantly different from each other and from the broader sample.

4.2.4.4 General opinions

Consistent with their position, detractors oppose SRM being studied (Q10: M = 2.37, SD = 0.91), used in a climate emergency (Q11: M = 1.62, SD = 0.71) or used today (Q12: M = 1.45, SD = 0.66). Conversely, supporters agree that SRM should be studied (Q10: M = 3.52, SD = 0.58), and support SRM's use both in a climate emergency (Q11: M= 3.10, SD = 0.53) and immediately (Q12: M = 3.00, SD = 0.63). For each of these questions, the difference between the means are significant at $p < 0.001$ (Q10: $t = 25.7$, Q11: $t = 40.4$, Q12: $t = 40.1$). More generally, supporters seem to hold the position that science plays an important role in SRM development. Along with strongly supporting SRM research, supporters believe that with enough research SRM will be safe and effective (Q15B) and see SRM as helpful (Q15A) but not natural (Q15H). Comparisons presented in Table 4.3 suggest detractors hold significantly different opinions on these questions.

Table 4.3 Mean comparisons of general opinions of SRM between supporter and detractor opinion groups.[1]

Exact Question Wording	Supporter		Detractor		t-Statistic
	Mean	SD	Mean	SD	
Q15A: SRM will help the planet more than it will hurt it.	3.00	0.65	1.75	0.87	25.2**
Q15B: With enough research, I believe Solar Radiation Management will turn out to be safe and effective	3.14	0.58	1.80	0.82	30.2**
Q15C: Solar Radiation Management should be used so we can continue to use oil, coal and natural gas.	2.32	0.90	1.65	0.82	13.7**
Q15D: SRM is the easy way out.	2.69	0.79	2.74	1.06	0.8
Q15E: Research will lead to a technology that will be used no matter what the public thinks.	3.13	0.74	3.00	0.87	0.9
Q15F: The earth's temperature is too complicated to fix with one technology.	3.17	0.74	3.58	0.71	10.8**
Q15G: Humans should not be manipulating nature in this way.	2.62	0.86	3.68	0.63	25.3**
Q15H: SRM is natural.	2.43	0.83	1.59	0.80	17.8**
Q15I: If scientists find that SRM can reduce the impacts of global warming with minimal side-effects, then I would support its use.	3.46	0.60	2.19	0.99	25.6**

* $p < 0.05$; ** $p < 0.001$ statistically significant at a 95% confidence level (2-tailed).

[1]Based on a 4-point Likert scale: 1 = strongly disagree; 2 = disagree; 3 = agree; 4 = strongly agree.

4.2.4.5 Opinions on global warming

Opinions on global warming also differ significantly between supporter and detractor groups, as shown in Table 4.4. Supporters agree that global warming is a serious (Q6A), anthropogenic (Q6B) problem that the government should do more about (Q6D). This can be contrasted with the detractor view that sees global warming as less of an issue (Q6A) and with less of a human basis (Q6B). Despite differing views on global warming, both groups agree that SRM should not be used as a way to continue burning fossil fuels (Q15C) and that the earth's temperature is too complicated to fix with one technology (Q15F).

Table 4.4 Mean comparisons of opinions on global warming between supporter and detractor opinion groups.[1]

Exact Question Wording	Supporter		Detractor		t-Statistic
	Mean	SD	Mean	SD	
Q6A: Global warming is a serious problem.	4.15	0.93	3.40	1.39	11.2**
Q6B: Humans are primarily responsible for global warming.	4.00	1.03	3.43	1.46	8.0**
Q6C: One person's actions have no impact on global warming.	2.38	1.10	2.68	1.26	4.5**
Q6D: My government should do more to deal with global warming.	4.03	0.95	3.33	1.43	10.1**

** $p < 0.001$ statistically significant at a 95% confidence level (2-tailed).

[1]Based on a 5-point Likert scale: 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree.

4.2.4.6 Opinions on risk and benefits

In the educational section of the survey, participants were presented with four benefits and five risks of SRM. Table 4.5 shows results from question 14, where subjects were asked to state how important each risk or benefit was in the formation of their opinions. In general, supporters assessed the benefits as being more important than did the overall sample and the detractor group, while detractors, on average, did not rank any benefit as being important to their decision. The risks, however, were very important across all three opinion groupings. Each ranked damages to the ozone layer and unknown risks as the two most important factors.

Table 4.5 Results of question 14, showing relative importance of each risk and benefit to the overall sample and the 2 opinion groupings in forming opinions of SRM.[1]

Benefits	Overall		Supporters		Detractors		Unknown
	Mean	SD	Mean	SD	Mean	SD	
Q14A: Slow global warming and give more time to reduce GHGs.	3.23	0.81	3.56	0.58	2.63	1.00	18%
Q14B: Slow warming more quickly than cutting emissions, because very big cuts in emissions cannot do much to slow warming in the next half century.	3.18	0.81	3.52	0.58	2.64	0.99	20%
Q14C: Stop a climate emergency before too much damage is done.	3.26	0.80	3.58	0.58	2.69	0.98	20%
Q14D: Cheaper than stopping using fossil fuels.	2.80	0.94	3.08	0.81	2.36	1.01	21%
Risks							
Q14E: Change how much it rains in some parts of the world.	3.52	0.69	3.51	0.64	3.50	0.83	16%
Q14F: Damage the ozone layer.	3.65	0.63	3.66	0.58	3.63	0.73	20%
Q14G: Remove people's motivation to change their current lifestyle.	3.24	0.85	3.29	0.76	3.10	1.03	16%
Q14H: Allow coal, oil and natural gas companies to keep releasing greenhouse gases.	3.17	0.91	3.19	0.86	3.01	1.05	19%
Q14I: Unknown risks	3.68	0.60	3.61	0.60	3.74	0.66	16%

[1]Based on a 4-point Likert scale: 1 = Not at all Important; 2 = somewhat unimportant; 3 = somewhat important; 4 = very important.

4.2.4.7 Supporter and detractor demographics

An analysis of the two opinion groups suggests that the supporters are fairly evenly distributed between all three countries (33% USA, 32% UK and 26% Canada). Politically, 52% of this group describes their political views as moderate, with 20% and 4% describing them as conservative and very conservative respectively. This ratio is similar for all three countries. The detractor group, however, is dominated by Americans (41% vs. 28% UK and 31% Canada) and individuals holding a more conservative political view (44% moderate, 25% conservative and

10% very conservative). Political views differ per country - reported as *very conservative:conservative:moderate* – Canada 8%:17%:51%, United States 14%:32%:35%, and United Kingdom 6%:23%:50%. Both groups had equal gender and age distributions. Religious belief distribution did not greatly differ between groups, with about 60% self identifying as Christian, and 23% non-religious. The difference between average educational levels was not significant. A mean comparison suggests that country ($t = 3.0$, $p < 0.005$) and political views ($t = 4.6$, $p < 0.001$) significantly vary between the supporter and detractor groups.

4.2.4.8 Trusted information sources

The public receives information about the risks and benefits of technology from many sources, so characterizing the most trusted sources is important. When asked, "How much would you trust information about SRM from each of the following groups?", 75% of all respondents ranked university researchers as trustworthy. Environmental organization (65%) and friends and family (63%) were also trusted by over half the subjects. Conversely, less than one third of respondents trust the federal government (34%), religious leaders (29%), private companies (29%), media and reporters (26%), and industries benefiting from SRM (22%). There are notable inter-country variations in the perceived trustworthiness of certain groups, as shown in figure 2. In particular, religious groups are trusted more in the United States than they are in other countries. Detractors are significantly less trusting overall. Of particular note, the detractors lack trust in the federal government (Q16A: $M = 1.91$, $SD = 0.90$), which is likely to be heavily involved in SRM programs.

Figure 4.2 Subjects' trust in different groups, by country. 'No trust' denotes the percentage of respondents that somewhat or completely distrust a particular group, while 'trust' denotes the percentage of respondents that somewhat or completely trust that group.

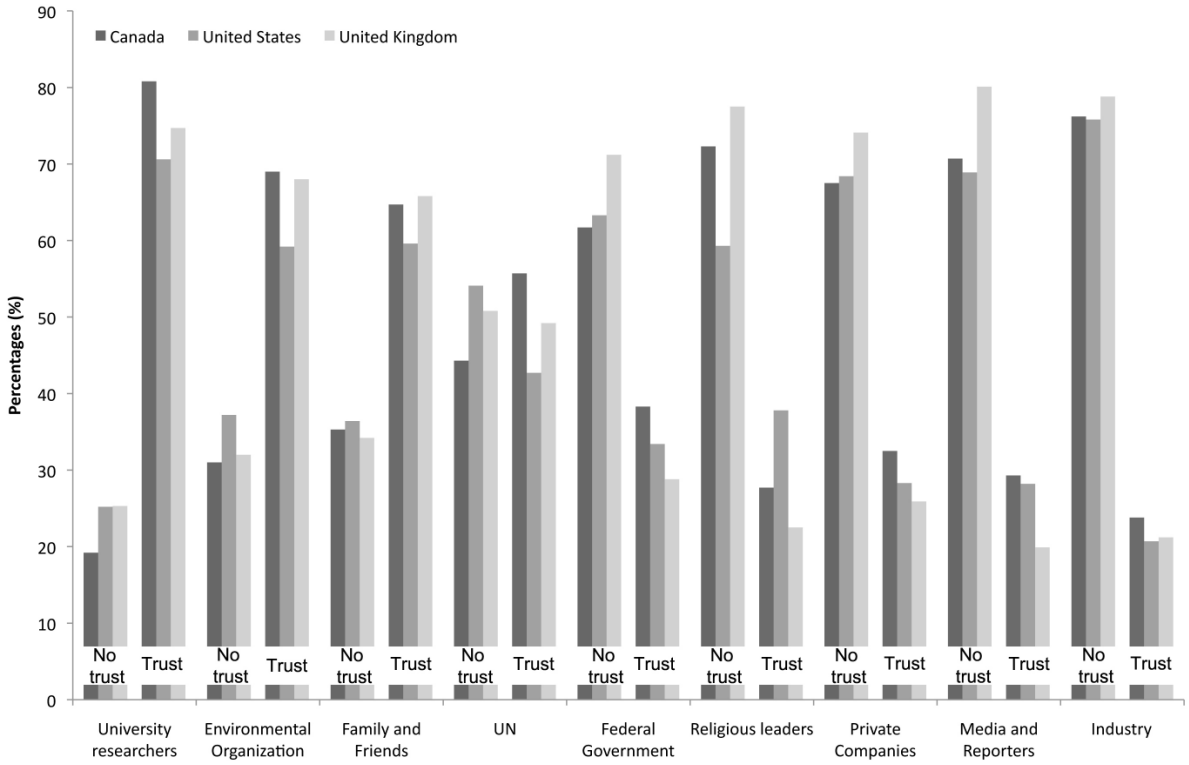


Figure 1 **Subjects' trust in different groups, by country. 'No trust' denotes the percentage of respondents that somewhat or completely distrust a particular group, while 'trust' denotes the percentage of respondents that somewhat or completely trust that group.**

3.2.3.3 Discriminant analysis

To further describe these two mutually exclusive opinion groups, a discriminant analysis was completed, using many of the factors described above as predictor variables. The function, given in Table 6, revealed a significant association between supporter and detractor groups and these variables ($l = 0.4$, $p < 0.001$). The most important predictor of a supporter is supporting the study of research (Q10) and detractors is the belief that humans should not be manipulating nature (Q15G). Notably, both opinions of global warming and demographic information, including political views and education level, are not important predictors in this analysis.

4.2.4.9 Discriminant analysis

To further describe these two mutually exclusive opinion groups, a discriminant analysis was completed, using many of the factors described above as predictor variables. The function, given in Table 4.6, revealed a significant association between supporter and detractor groups and these variables ($\lambda = 0.4$, $p < 0.001$). The most important predictor of a supporter is supporting the study of research (Q10) and detractors is the belief that humans should not be manipulating nature (Q15G). Notably, both opinions of global warming and demographic information, including political views and education level, are not important predictors in this analysis.

Table 4.6 Discriminant loadings for the important predictor factors in the discriminant function to describe supporter and detractor opinion groups.[1, 2]

Important predictor factors	Discriminant loading
Q10: Do you think scientists should study Solar Radiation Management?	.697
Q15G: Humans should not be manipulating nature in this way.	-.611
Importance of benefits (Mean of Q14A-D)	.596
Q15H: Solar Radiation Management is natural.	.497
Trust in organizations (Mean of Q14A-I)	.423
Q7C: We must develop new technologies to solve global warming.	.368
Q15C: Solar Radiation Management should be used so we can continue to use oil, coal and natural gas.	.332
Q15F: The earth's temperature is too complicated to fix with one technology.	-.314

[1] The other predictors included in the function are: Q6A, Q6B, Q6D, Q7A, Q7B, Mean of 14E-I, Q15F and political views.
[1] The cross validated classification shows that overall 86% of the cases were correctly classified.

4.2.4.10 Conspiracy theories

One of the voices emerging in the SRM debate is that of 'chemtrails' believers. This small group believes that organizations, such as governments, are already distributing chemicals in the stratosphere for a variety of purposes, ranging from culling the population to mind control. We found that 2.6% of the subjects believe that it is completely true that the government has a secret

program that uses airplanes to put harmful chemicals into the air, and 14% of the sample believes that this is partly true. Distributions across the three countries do not vary substantially.

4.2.5 Discussion

We found that the assessed familiarity of geoengineering is likely around 8%, which is greater than past empirical assessments. While this survey represents a single assessment, we contend that the increase news articles and internet searches (Figure 4.1) and increase in assessed familiarity of past studies suggests a growing public interest in geoengineering. Taken together, these results suggest an increasing public familiarity and imply that interest in geoengineering is no longer confined academia and policy elites. Future studies should track public awareness and emerging opinions in a systematic way.

An ongoing debate in elite circles argues that the term geoengineering is ineffective because it is difficult for the public to understand and derive its correct meaning. These research results support that position. The term geoengineering is strongly confounded with geotechnical engineering and geography, rather than intervention into the earth's climatic system. The term 'climate engineering' seems to capture this essential aspect of the technology, through higher rates of correct definitions and fewer avenues for misunderstandings. This research also suggests that weather modification and cloud seeding may provide a strong anchor for people to begin to conceptualize SRM and geoengineering. While this framing does not characterize the global scale of SRM and may perpetuate known cofounds between weather and climate, it does introduce the technology's salient characteristics of being a deliberate intervention aimed at deriving human benefits, with potential unintended consequences. Researchers have used a wide variety of analogies to describe SRM to the public including 'human-made volcanoes,' 'methadone therapy for our fuel addiction' and 'chemotherapy.' The surprisingly high number of

subjects that used the term 'cloud seeding' when asked to define climate engineering suggests that this term may also be useful in communicating relevant aspects of SRM to the public. Further testing of the salience of this framing is required.

As expected in opinion surveys of emerging technology, portions of the population do not hold strong certain opinions. While the share of "uncertain" responses moderately decreased after subjects received the educational section provided to them in the survey; the proportion of uncertain respondents remained significant for many questions. SRM is a new technology, and while public awareness may be growing, public opinions are in their formative stage and are sensitive to changes in framing, future information on risks and benefits, and changes to context (e.g., climate change).

In this initial assessment of emergent supporter and detractor positions, supporters of SRM can be characterized, by a belief in scientific research, a prioritizing of SRM benefits in their decisions and an opinion the SRM is natural. Detractors can be characterized by the opinion that humans should not be manipulating nature in this way. Interestingly, demographics and views on global warming are not predictors of the supporter or detractor position. It is likely the value of more precise risk and benefit information to these opinion groups may differ. For supporters, it is likely that more precise estimations of the extent and impacts of potential risks will help to both solidify their opinions and decrease their uncertainty. As the detractor position is defined as a complete rejection of SRM, their opinions are less likely to be affected by trade-off analyses that compare risks and benefits, and more likely to be driven by the ideologies underlying their rejection of the technology.

It seems plausible that support for and rejection of SRM cut across environmental values in two very different ways. One framing assumes that environmentalists oppose interfering with

nature, while political conservatives would support a cheap technological solution to climate change. Under this simplistic framing, one would expect conservatives to support SRM and environmentalists to be opposed. An alternative framing is that environmentalists will support SRM because they are most concerned about action on climate change, while conservatives will oppose SRM because it increases government power. The data suggests, but does not prove, that both framings are in play within subsets of the supporter and detractor groupings.

The potential risks of SRM are an important consideration for all groups when developing their opinions about SRM. Scientists' understanding of the environmental and social risks of SRM is still in its nascent stage. However, the public dialogue is likely to be dominated by discussion of the potential impacts of SRM experiments or interventions. There may be a disconnect between how much is currently known by the academic community about SRM and how much the public would like to know.

Our results are consistent with findings that public audiences tend to trust scientific institutions on topics of high uncertainty (Siegrist *et al.*, 2000). As future policy and governance debates concerning SRM continue, scientists are likely in a unique and trusted position of influence. Also noteworthy was the lack of trust that the public reported in federal governments, especially within the detractor group. As the political and academic circles continue their discussions on the future of SRM, and design potential governance structures and research programs, ensuring that the science remains disentangled from the politics will help to preserve the public's trust in scientists on the topic of SRM. When subjects were asked what they would like to ask or say to a researcher or decision-maker working with SRM, one response in particular summed this position up: "Talk straight, make sure, don't screw up and don't forget anything."

As discussions about the wisdom of research into SRM or its eventual deployment continue, researchers and policy makers can no longer assume that the public is unaware of SRM. Our survey data suggest that public awareness of geoengineering is larger than expected, and growing. It also suggests: (1) scientists are considered a trusted source of information but governments are not; (2) perception of the risks of SRM will likely play a central role in shaping opinions about its development; (3) support for SRM is associated with an optimism about research, a valuing of SRM' benefits and a belief that SRM is natural; whereas, skepticism of it is associated with a belief that nature should not be manipulated; and finally, (4) public opinion on SRM is strongly contingent on how, where and in what context SRM is discussed. Incorporating these findings into research and communication efforts will increase the likelihood that the public will be effectively engaged in the SRM discussion, and help us all grapple with how to proceed with future climate change policy.

4.3 Revisiting our study in light of new evidence

Since this work was published, two large surveys in Japan (Sugiyama, 2012) and the UK (Pidgeon *et al.*, 2012) have found evidence that views about climate change, specifically a higher concern about climate change and a pro-environmental orientation are important predictors of support of geoengineering. We expected to see this relationship in our research, and the lack of this predictor in our discriminant analysis was surprising. The difference between the studies may be a result of the labile opinions, or indicative of a more complicated relationship between SRM and environmental views, as we suggested in the paper's discussion (section 4.2.4). Pidgeon *et al.* (2012: 4192) observes a similar trend and also hypothesized:

> One could plausibly find some environmentalists who oppose geoengineering proposals because they believe this will interfere unduly with Nature, while other environmentalists will be prepared to accept the same technology if it can realistically offer a counter to climate change. Equally some climate sceptics might support geoengineering as an insurance policy that would

allow Western high-consumption lifestyles to continue unabated, while others might view it as an unnecessary expense because it addresses a problem they believe does not exist.

4.4 Survey tool

For the complete survey tool see Appendix A. It has been used as the basis of research in Japan and Germany. In Japan, the survey was fielded to over 4000 individuals (Sugiyama, 2012) and in German to 1040 individuals (Merk, 2013). At the time of preparation, results have been collected but not published.

4.5 Non-scientific concerns raised by lay individuals

As already identified, one of the limitations of survey questions is their rigidity. The final question of our survey was designed to provide respondents some increased freedom to express any thoughts that they felt were important. The question: 'If you had the chance to talk to solar radiation management researchers and decision makers, what would you say or ask?' provided space for participants to express in greater depth their questions, comments and/or opinions. The responses from this specific question were published in: Wylie Carr, Ashley Mercer & Clare Palmer (2012). "Public concerns about the ethics of SRM." *Engineering the Climate: The Ethics of Solar Radiation Management*. Lexington Books: Maryland. The full chapter is available in Appendix C. This publication brings together public responses and academic ethics literature on SRM, with the goal of identifying converging and diverging ethical issues between expert ethicists and lay individuals. We believed that discourse of this kind "could improve both public and philosophical engagement with geoengineering and improve the research and development of solar radiation management technologies" (Carr *et al*., 2012: 171). This thesis will not recapitulate the ethical comparisons, but will present some of findings to highlight specific areas of concerns identified by the lay population.

4.5.1 Methods

The responses were collated and categorized by the researchers based on their broad themes. About 70% of the included survey participants responded, with an average of 22 words per response (answers with no content or clear intention to not answer were removed, e.g. "don't know," "no comment," jumbles of letters). The answers to this question highlight the significance of the concerns that members of the public have about SRM and provide insights into the nature of those concerns. Anecdotally, the complexity and thoughtfulness of many of the responses are striking. This suggests that the concerns of SRM are salient to members of the public, even when encountering this topic for the first time. There is no frequency analysis of themes because it was felt that the relevance of the data lies in the breadth and characterization of responses, not their relative frequency.

4.5.2 Summary of select results

The specific responses are categorized into seven broad themes. Participants frequently touched on multiple ideas in their responses. The themes are:

- Concerns with negative side effects (including unforeseen risks);
- A sense that SRM is playing God and/or messing with nature;
- Concern that SRM is the wrong solution or a technological Band-Aid;
- Distributional concerns of harm and benefit (including harm to vulnerable population, future generations);
- Concerns related to trust of and public participation in SRM science;
- Concerns over how SRM technologies may be governed; and
- Comments related to climate denial.

The inclusion of the specific responses is important for understanding the nature of these themes. Table 4.7 provides some illustrative quotes for each thematic area. The participants' responses have been edited for spelling only.

4.5.3 Discussion

Upstream technologies are known to be a node for individuals to express broader non-scientific societal tensions including: shifting patterns of control, trust and influence of agencies, hubristic claims of technology and limits of knowledge (Kearnes *et al.*, 2006). Historically, these non-scientific tensions come to define the technology, resulting in a shift in the debate from a technological focus towards these greater societal issues. For example, studies of attitudes towards genetically modified food have identified these issues as a major component of on-going public opposition (Ferber, 1999; Gaskell *et al.*, 1999). Similar public tensions have been identified in nanotechnology (Pidgeon *et al.*, 2009). Revisiting the survey responses, there is evidence of people raising issues of:

- trust in scientists (E1, E2);
- questions of technological control and governance (E2, F1, F2);
- concerns over hubristic claims (B1, B2, C2);
- questions of knowledge limitations (A1, A2); and
- concerns over misidentification of the solution, suggesting more importance be placed on mitigation (C1, C2, D2).

(the alphanumeric code refers to specific illustrative responses in Table 4.7). There are specific technical questions (A1, D1), but overall, the responses are suggestive that SRM may be a node for non-scientific tensions. This is supported by Pidgeon *et al*. (2013: 4) who drew similar

conclusions from a one and a half day deliberative engagement exercise about SRM. They concluded that:

> Our findings suggest that the development of stratospheric aerosol technologies holds the potential for significant public concern and controversy. Concerns were centred on the inability to address the fundamental problem of increasing greenhouse-gas emissions, possible unintended consequences and the perceived 'unnaturalness' of the technique. Perhaps more importantly, aerosols were also seen to raise significant problems of international governance and control.

Response A3: 'Is it safe?' encapsulates the importance of these non-scientific tensions in the greater acceptability of SRM. Science may contribute a better understanding of some aspects of safety, specifically impact characterization, however concepts of safety include questions about acceptable risk, control and knowledge thresholds. These are deeper social and ethical questions that are not answered by science.

As we concluded in the chapter "Public concerns about the ethics of SRM",

> …ethical considerations are central to public concerns about SRM. This has emerged in other public engagements (National Environmental Research Council, 2010; Parkhill *et al.*, 2011) but it is a point worth emphasizing. The core questions raised by geoengineering technologies in the public arena are, as the Royal Society (2009) anticipated, social, ethical, and political, rather than primarily scientific and technological. Over two-thirds of the responses to a very broad, open-ended question on an international survey focused on what we have classified as ethics issues. This indicates that ethical questions are at the forefront of people's minds when they think about geoengineering, and it is these questions that the public will want to see addressed by scientists and decision makers (Wynne, 2006). If SRM is to gain *public* acceptance, it will need to gain *ethical* acceptance. And at the moment, there are many public ethical concerns that would need to be allayed—if, indeed, they can be (Carr *et al.*, 2012: 185).

Table 4.7 Concerns raised by lay people in open answer question: If you had the chance to talk to Solar Radiation Management researchers and decision makers, what would you say or ask? Illustrative responses given below each theme.

A) Negative side effects

A1 We were told that smoking was not harmful to our health. We were told that asbestos was not harmful to our health. . . . What kind of health problems might be expected or are we just changing one problem for another perhaps more costly?'

A2 The thing that really worries me is the unforeseen effects. However much research you do, you cannot allow for all possible outcomes and once it's done it can't be undone. You cannot know for certain what the effect will be, however much research is done.

A3 Is it safe?

B) SRM is playing God and/or messing with nature

B1 What gives you the right to mess about with nature and cause a potentially worse disaster than you're trying to prevent?

B2 I would say, Stop playing God, there is no easy way out. We must be logical and not go on making more problems for ourselves—You are making us all feel like goldfish in a blender. Thanks for nothing!

C) SRM is a technological band-aid

C1 Understanding we are in serious trouble with global warming, I support efforts to stall or retard advancement. However, rather than a band-aid we need to STOP at all costs the emissions.

C2 This seems like another quick fix to an environmental issue we have. We need to stop trying to solve problems with ways that could cause more problems. Remember DDT?

D) Distributional concerns of harms and benefits

D1 How severely will this technology change weather patterns in the poorer parts of the world?

D2 My children and grandchildren are the future of this planet. We owe it to future generations to further explore ALL avenues of science AND restraint. We need to be much more aware and prudent, in our consumption and use of our natural resources**.**

E) Trust of and public participation in SRM science

E1 What will be the benchmarks for success/failure, who will identify these criteria and how will these trials be funded?

E2 Why do you think the public should trust your judgment? How could you trust even yourselves to not use the science for personal gain and which government in the entire world would not use it for political gain?

F) SRM technology governance

F1 What industries would develop the technologies and who would be responsible for implementing them? What kind of national and international oversight would there be and with what authority?

F2 Who would decide which part of the world would have their rain volume changed because of Solar Radiation Management and would that mean that some countries would need to become uninhabitable?

G) Climate denial

G1 You are starting from a premise that is unproven, many would even say unfounded. That is, that human activity results in global warming (climate change). This idea is nothing more than a political manoeuvre to gain votes. Hard, peer-reviewed science indicates that the earth goes through cycles of warming and cooling. Nothing to be alarmed at.

4.6 The expanding understanding of acceptability

The research described above was the first major empirical study in the emerging attitudes and perceptions of SRM. Research has continued in this area using two distinct methodologies: surveys and deliberative public engagement exercises.

- The survey work has been expanded to consider the role of cultural worldviews, preference trade-off between CDR and SRM, and attitudes in different nations (see: Bostrom *et al*., 2012; Kahan *et al.,* 2012; Pidgeon *et a*l., 2012; Sugiyama 2012; GAO, 2011).
- The deliberative public engagement studies are often multi-day group focus groups that provide a nuanced examination of emerging opinions of technological acceptability examining questions such as: What is a development for? Who will be responsible if things go wrong? What concerns you about the technology? (Pidgeon *et al.*, 2013) (See: Pidgeon *et al*., 2013; Macnaghten and Szerszynskic, 2013).

While the work presented in this chapter has focused on SRM specifically, most of the subsequent research has included a wide variety of geoengineering approaches spanning SRM and CDR.

Considering this broader body of research, important findings relating to acceptability include:

1. CDR methods were preferred to SRM (Royal Society, 2009; National Environmental Research Council, 2010; GAO, 2011; Pidgeon *et al.*, 2012). Both receive considerably less support than other technological responses to climate change, including energy efficiency measures and renewable technologies (Bostrom *et al.*, 2012).

2. Surveys and most deliberative engagement exercises to date show cautious support for geoengineering research (Spence *et al.*, 2010; GAO, 2011; Mercer *et al.*, 2011; Sugiyama, 2012; Merk, 2013; Pidgeon *et al.*, 2013), with one exception: Macnaghten and Szerszynskic (2013). People are more cautious about deployment (Mercer *et al.*, 2011; Corner *et al.*, 2012; Pidgeon *et al.*, 2012) and make distinctions between lab-based and in-situ testing (Merk, 2013).
3. Naturalness and reversibility are strong motivators of perceptions (National Environmental Research Council, 2010). The debate about geoengineering's intervention into the natural world is likely to be a key factor in public views (Corner *et al.*, 2013). SRM is often perceived as unnatural (a predictor of opposition) (Pidgeon *et al.*, 2013), however, both opinions of geoengineering as either a means of 'preserving' nature, or as a threat to it, are present in deliberative debates (Corner *et al.*, 2013).
4. SRM is seen as a technological fix, and evidence suggest geoengineering will only be acceptable if it is accompanied by mitigation (Pidgeon *et al.*, 2013).
5. A broad set of non-scientific social tensions related to: control, scientific knowledge, perception of hubris and trust are regularly brought up as concerns related to SRM (Carr *et al.*, 2012; Pidgeon *et al.*, 2012; Macnaghten *et al.*, 2013; Pidgeon *et al.*, 2013).

4.7 Chapter summary

As I began the work reported here in 2010, it was widely assumed that the public was so unfamiliar with SRM that they were unable to contribute to the emerging debate except through the use of highly structured focus groups. Our study and others like it, show that it is possible to get something useful from a survey of a large number of people. Although the stability of opinions should be treated with caution, this growing body of work studying public response and

opinions of SRM (comprising a range of mixed methods) are reaching similar findings to those reported here. This work also reaffirms familiar findings from research on other emerging technologies. Given broader findings from SRM research as a whole, the important conclusions about public opinions of SRM include:

- Familiarity with SRM in the general public is limited (we estimate about 8%), but opinions and attitudes are emerging;
- In comparison, people seem to prefer CDR and conventional climate change strategies (such as mitigation) over SRM;
- Themes of naturalness are important to perceptions;
- People seem to make a distinction between research and deployment of SRM, often supporting open transparent research in this area to varying extents;
- Non-scientific concerns such as the extent of the intervention on Nature are likely important factors of acceptability - some of which are unlikely to be addressed by a better scientific understanding; and
- Common concerns about SRM are brought up repeatedly. These include: reversibility; technological relevance and applicability; the uncertainty of environmental and human impacts; the potential for unknown risks; trust in agents (e.g. scientist, governments, corporations) participating in its development and future deployment; the avenues (and lack thereof) for public participation; and the control and governance of its research and use.

CHAPTER 5 – EXPERT JUDGMENTS OF SRM

This chapter presents initial results from a year-long mixed-method research project focusing on understanding expert judgments about SRM in the context of a broader climate strategy. I start by outlining the interview and online expert survey methodologies used to collect the data. I then provide a general description of the results and a deeper examination of experts' judgments. I expect to complete a paper on this work over the next half year.

5.1 Introduction

The IPCC's mandate is "to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts" (IPCC, 2013a). The Fifth Assessment report will include considerations of geoengineering, both of the carbon and solar variety, as a potential response option for managing climate impacts (IPCC, 2010). This may be seen as the full realisation of the progression of SRM from the fringes of academic discussion (Keith, 2000; Crutzen, 2006) to inclusion in mainstream climate debates. As SRM becomes more central in the climate debate, understanding the ways that experts think about the trade-offs (and synergies) between different climate response options has important policy implications.

Studies of the acceptability of SRM in isolation from other responses highlight specific areas of public concern and basic perceptions about the technology. They do not consider, however, the more policy-relevant question of how perceptions and opinions change when considering other responses in a broader climate strategy. Past studies examining opinions and attitudes towards geoengineering have focused on public audiences in developed nations isolated from the broader climate context. This lack of contextualisation is largely due to methodological

limitations of studying attitudes and opinions of a technology like SRM in populations with limited familiarity. To overcome this challenge, surveys and deliberative engagement exercises have provided participants with information on the risks, benefits and technical limitations of SRM. While this process helps to inform opinions, the critique levelled against such approaches is that the framing and content of information may bias the resulting opinion. Recognizing the limitations of lay audiences, and understanding that a discussion of SRM must take place in a broader context, this research draws on an expert population that has specialized knowledge in this area.

5.1.1 Experts as subjects

Broadly defined, experts are individuals that have advanced skills and knowledge gained through experience and training in a specific domain. Expertise is in part characterized by superior ability to identify and extract information, understand its relevance, and simplify the decision context (Shanteau, 1988). Specifically, climate experts should be thought of as a subset of the public that have extensive scientific knowledge about climate change, and have informed opinions on the available approaches to limit its impact. A response option expert (e.g. SRM expert) is a subset of this population, who has expertise about a particular approach. SRM experts are an influential source of information on risks, benefits, and technical feasibility. As Corner *et al.* (2012: 9) suggest, "the narratives developing within this diverse range of individuals [SRM experts]…are likely to continue to prove influential on the broader debates about the societal impact of geoengineering."

5.1.2 SRM Trade-off judgments

The acceptability of SRM is based on trade-offs between multiple criteria that are valued differently by any given expert. These criteria can include: the importance of the decision; the

perceived risks and benefits of SRM; the perceived objectives for a climate strategy; the assessment of the threat climate change may pose; the comparison between feasibility and effectiveness of SRM and other relevant technologies; and individual personal values. There are a limited number of studies that look at how some of the above criteria influence preference and acceptability of SRM in expert populations. Recent work by Bellamy *et al.* (2013), applies a Multi-Criteria Mapping methodology to appraise SRM in conjunction with other climate options including mitigation and CDR approaches. The study found that SRM was consistently ranked lower than mitigation options. Its assessments across a range of criteria were variable, with the exception of ethical considerations, which was universally ranked poorly. Of note, the efficacy of SRM was largely subject to the experts' perceived climate strategy objective (e.g. temperature reduction, GHG limitation). This study showed evidence of "reluctant acceptance" of SRM in experts, which has been previously observed in public engagement exercises (Parkhill and Pidgeon, 2011; Macnaghten and Szerszynskic, 2013).

5.1.3 Goals

Expanding on past research, this study examined expert assessments of the potential role of SRM in climate policy. In particular it focuses on:

1. Eliciting preferences for response options given different objectives for climate scenarios.
2. Eliciting experts' judgments about the effectiveness and risks of SRM.
3. Posting judgments about the effectiveness of broad response options from conservation through adaptation.
4. Eliciting explicit quantitative judgment about the trade-off between response options in the context of the experts' opinions.

5.2 Methods

The data was collected using a two-stage survey protocol, which included an open-ended interview stage that informed an online survey (Morgan *et al.*, 2002).

5.2.1 Interview

The interviews were hour-long, individual semi-structured interviews completed with twelve SRM experts (see Table 5.1 for participant list). They took place between August – October 2012 using a mix of telephone and in-person interviews.

Each expert was asked to provide their opinion on the scope and extent of the climate problem and potentially important objectives for a climate strategy. Specifically, they were asked:

1) What are your concerns about climate change and why are they important?
2) What are some objectives you might consider in a future climate strategy and why are they important?
3) What is personally important to you when considering the climate issue?

During the interview, experts were asked to continually explain the importance of each proposed objective to help clarify the fundamental objectives and values underlying their comments.

5.2.1.1 Expert selection

Experts were invited to participate based on suggestions compiled by four prominent experts in SRM research. In nominating potential participants, the prominent experts were asked to consider individuals with a wide range of expertise, and to not limit their suggestions solely to academics. The interviewed experts were characterized by a strong professional focus in climate-related work, with an average 23 years experience in this area [range 4-45 years]. More specifically, this group of experts reported devoting, on average, three quarters of their

professional time to climate-related topics [range: 20-100%] and had significant publication records[13] [average: 45 publications, range: 5-170 publications]. Their disciplinary backgrounds were intentionally diverse, covering expertise in journalism, international and humanitarian development, climate modeling, environmental policy, law, biology, and technology studies. Each had knowledge of geoengineering techniques with an average of seven years of specific SRM experience [4-20 years].

Table 5.1 Expert participants in interviews

Expert	***Institution***
Jason Blackstock	*Oxford University*
Mike MacCracken	*Retired*
Georgina Mace	*University College London*
Oliver Morton	*The Economist*
Andrew Parker	*Harvard University*
Edward A. Parson	*University of California, Los Angeles*
Steve Rayner	*Oxford University*
Alan Robock	*Rutgers University*
Pablo Saurez	*Red Cross / Red Crescent Climate Centre*
John Shepherd	*University of Southampton*
Jack Stilgoe	*University College London*
Jim Thomas	*ETC Group*

5.2.2 Coding

The interviews were coded by the researcher for explicitly stated or implied objectives important to a future climate strategy. Specific framings of the objectives were also identified. Interesting attitudes and values were noted and integrated into the survey development. All coding was done in Dedoose (an online qualitative research coding platform).

[13] Defined as 'significant' based on their disciplinary considerations.

5.2.3 Summary of relevant findings influencing survey design

While not intended to be a full summary of interview results, the following are some of the findings from the interviews that were important in developing the survey design.

1. A list of objectives was summarized across interviews and included in a ranking exercise in the online survey. They are found in Table 5.3.
2. Three objective framings dominated the discussion: lowering temperature/emission, limiting human vulnerability and limiting ecosystem damage. These general framings were emphasized and prioritized differently by each expert. Given the varied responses, it seemed reasonable to explore how judgments of response options differed when considering with different climate strategy objectives. This became the basis for the temperature, human vulnerability and ecosystem damage objective framings used throughout the survey.
3. Opinions about the importance, the extent and nature of specific threats posed by climate change were noted in the interviews and tested in the survey.
4. Climate objectives were often framed in human-centric ways. Questions were designed to explore the extent and nature of this anthrocentric description and included in opinion questions.

5.2.4 Expert survey

An online survey questionnaire was completed by 43 experts with a breadth of climate expertise (see Table 5.2 for participant list). The data was collected over the summer of 2013 (July 1-August 31, 2013) using the NearZero online expert elicitation platform. The questionnaire was designed to survey opinions and preferences about a hypothetical climate strategy taking place over a socio-political timescale (30 years), and a planetary timescale (300

years) – see Appendix B for complete tool. The tool consisted of nine activities, in which experts were asked to provide the following:

1) Overall climate objectives - Prescriptive goals for a global climate strategy over both the socio-political and planetary timescales;
2) Objective importance – Assessments of the importance of a set of objectives (derived from the expert interviews) for the socio-political and planetary timescales;
3) Response option preferences - Preferences for specific response options: conservation, efficiency, decarbonisation, CDR, SRM and adaptation considering different objectives for a climate strategy. The four objective scenarios were:
    - Reduce average rate of warming by 50% in 30 years relative to the expert's business-as-usual (BAU) scenario;
    - Hold temperature rise to no more than 2^{o}C in 300 years;
    - Lower the rate of biodiversity loss in 30 years; and
    - Raise the Human Development Index (HDI) in Niger in 30 years.[14]
4) Temperature reduction portfolio – Portfolios describing percent contribution of various response options to a reduction in the rate of warming by a factor of two (compared to the expert's best BAU estimate) over the next 30 years.
5) Political capital commitment – Estimations of the political capital experts would consider dedicating to a specific response option.
6) Measure of individual response option's perceived effectiveness – Estimates of the maximum effectiveness of each response option, given a dedicated commitment of half

[14] The Human Development Index is a comparative measure of life expectancy, education and income for countries worldwide. Niger was indexed at 0.304 in 2012.

a percent of global GDP of funding (350 billion dollars) distributed by apolitical and efficient mechanisms.

7) Perceived extent of future climate threat – Estimates of future atmospheric carbon concentrations, and estimates of threat to various natural and social dimensions (e.g. vulnerable people, non-human nature).
8) Opinions and value measurements – Opinions on a set of questions specifically related to technological optimism, views of nature and climate change impact.
9) Estimated expertise – Self-reported measures of expertise.

Experts were given the option throughout to provide textual clarification to any response. This function was used with regularity and provided further nuance to numerical responses.

5.2.4.1 Expert selection

To select a group of recognized climate experts covering a range of dimensions, three authors from each chapter of the IPCC Assessment Report 5 were randomly chosen and invited to participate in the survey. Invites were sent to 179 experts, with 34 responding (response rate of 19%). Their geographical distribution reflects the international nature of the IPCC. It should be noted that these experts were not invited to speak, nor did they speak, on behalf of the IPCC. The author list was publically available, and provided a uniquely vetted list of climate experts across a complete range of climate dimensions. To ensure the inclusion of a specific sample of experts familiar with SRM, a set of invitations was extended to experts identified during the interview process. Nine individuals from this group chose to participate (response rate of 60%). These experts were from either the US or the UK. Four experts took part in both the interview and survey. Using self-reported measures, the distribution of expertise is characterized by the

Table 5.2 Expert participants for online survey

Expert	*Institution*	*Expert*	*Institution*
Govindasamy Bala	*Indian Institute of Science*	Rupa Mukerji	*HELVETAS Swiss Intercooperation*
Olivier Boucher	*Centre National de la Recherche Scientifique*	Ian Noble	*Retired and Independent Consultant*
Ken Caldeira	*Carnegie Institution for Science*	Úrsula Oswald Spring	*Regional Centre for Multidisciplinary Research at the National Autonomous University of Mexico*
Edmo J. D. Campos	*Oceanographic Institute of the University of Sao Paulo*	Jiahua Pan	*The Chinese Academy of Social Sciences*
Mat Collins	*University of Exeter*	Edward A. Parson	*University of California, Los Angeles*
Peter Cox	*University of Exeter*	Pablo Suarez	*Red Cross / Red Crescent Climate Centre*
D. M. Duc	*Hanoi University of Science*	Marie-Louise Rakotondrafara	*Madagascar Meteorological Department*
Dabo Guan	*University of Leeds*	Phil Rasch	*Pacific Northwest National Laboratory*
Erik Haites	*Margaree Consultants Inc.*	Holger Rogner	*International Institute for Applied Systems Analysis*
Ove Hoegh-Guldberg	*University of Queensland*	Joyashree Roy	*Jadavpur University*
Baris Karapinar	*University of Bern / Bosphorus University*	Steve Sherwood	*University of New South Wales*
Patrick Kinney	*Columbia University Mailman School of Public Health*	John M R Stone	*Retired*
Tim Kruger	*University of Oxford*	Taishi Sugiyama	*Central Research Institute of Electric Power Industry (CRIEPI)*
Anders Levermann	*University Potsdam*	Massimo Tavoni	*Fondazione Eni Enrico Mattei and Euro-Mediterranean Center on Climate Change*
Marc Levy	*Columbia University*	Claudia Tebaldi	*Climate Central*
Juan Llanes	*University of Havana*	Richard Tol	*University Sussex*
David Lobell	*Stanford University*	Naomi Vaughan	*University of East Anglia*
Michael MacCracken	*Retired*	David G Victor	*University of California, San Diego*
Bruce Mccarl	*Texas A&M University*	David Winickoff	*University of California, Berkeley*
Muhammad Mohsin Iqbal	*Global Change Impact Studies Centre*	Shang-Ping Xie	*University of California, San Diego*
Oliver Morton	*The Economist*	Gary Yohe	*Wesleyan University*

following: (format: percentage of sample reporting medium to high expertise in a specific response option: number of experts that identify that response option as the primary focus of their work)

- conservation 21% : 2 experts,
- efficiency 30% : 5 experts,
- decarbonisation 37% : 5 experts,
- CDR 26% : 4 experts,
- SRM 40% : 4 experts,
- adaptation 56% :12 experts,
- making trade off between response options 51%: 8 experts,

(NB. categories are not mutually exclusive, reported expertise was allowed for any number of response options). Over 75% of the experts have been working on climate-related research for over 11 years, with about 40% having over 21 years of expertise. All have authored climate-related publications, and the majority were well-published.

5.3 Results

5.3.1 Rating the importance of objectives

Table 5.3 provides average rankings of each objective's perceived importance to a climate strategy on the socio-political and planetary timescales. In general in the near term, all objectives were seen, to varying degrees, to be important. The most important objective was "limiting long-term emissions" ($M = 6.2$, $SD = 0.9$) and "impacts on vulnerable people" ($M = 6.0$, $SD = 1.4$). The former was ranked significantly higher than most objectives, although it is not significantly different than the following objectives: limiting impacts on vulnerable people, future generations and enhancing people's ability to adapt. Limiting costs was seen as

Table 5.3 Mean comparison of the importance of objectives to a climate strategy over both a socio-political timescale (30 years) and a planetary timescale (300 years).[1]

	Socio political		Planetary	
Objective	*Mean*	*SD*	*Mean*	*SD*
Limit any future emissions of long lived greenhouse gases	6.2	0.9	6.3	1.1
Limit the impact of climate change on the most vulnerable people	6.0	1.4	5.6	1.4
Enhance people's ability to adapt to climate change	5.9	1.2	5.7	1.2
Limit negative impacts on future generations	5.7	1.2	5.7	1.8
Limit disruption to natural environments	5.5	1.3	5.7	1.5
Limit loss of ecosystem services	5.5	1.4	5.6	1.5
Limit negative impacts on human infrastructure	5.3	1.4	5.3	1.3
Limit novel risks introduced by components of the planned strategy	5.3	1.2	5.6	1.2
Limit any future emissions of short lived greenhouse gases	5.3	1.5	4.7	1.9
Ensure the full range of climate impacts are addressed	5.2	1.5	5.4	1.6
Ensure equitable sharing of the climate change burden between rich and poor countries	5.1	1.9	4.8	1.9
Promote broad stakeholder participation in climate related decisions	5.1	1.6	4.7	1.7
Limit the overall financial costs of the climate strategy	4.9	1.2	4.3	1.6

[1]Based on a 7-point point scale: 4 = neutral; 5 = moderately important; 6 = very important; 7=extremely important.

the least important objective across both time periods. On the planetary-timescale limiting emissions was the most important objective (M = 6.3, SD = 1.1) by significant margins.

5.3.2 Basic preferences

There is a strong preference for efficiency and decarbonisation amongst experts. Conversely, SRM is consistently the least-preferred response with only 22% of experts ranking it in their top three preferred options. Expertise did not influence SRM preference as individuals with high self-reported SRM expertise consistently ranked it as their least preferred option. Figure 5.1 shows the range of experts' preferences for the climate responses given various objective framings. Specifically, Table 5.4 shows that efficiency is the most-preferred short-term strategy for decreasing rate of temperature rise, but predictably preferences shift towards decarbonisation when considering temperature stabilisation on a planetary timescale. Adaptation is overwhelmingly the preferred response option given the objective of addressing near-term human vulnerability.

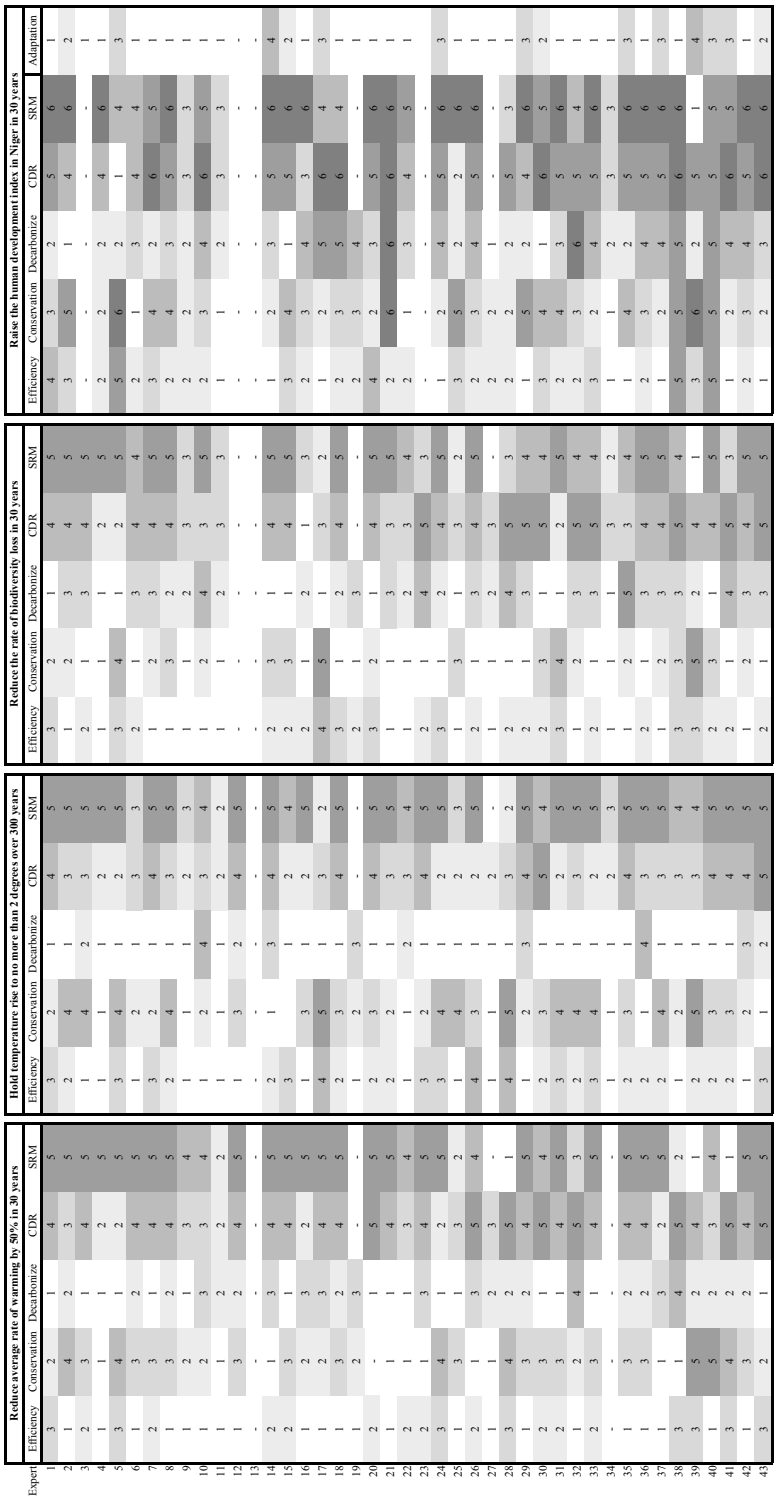


Figure 5.1 Individual response preferences across each objective strategy. Darker colours indicate lower preferences. Dashes indicate no preference was given.

Table 5.4 Percentage of experts choosing a given response option as the most preferred given a specific climate strategy objective framing.[1, 2]

	50% temperature reduction in 30 years	*Holding temperature rise to 2°C in 300 years*	*Lower biodiversity loss in 30 years*	*Raising HDI in 30 years*
Conservation	23%	20%	49%	9%
Efficiency	51%	37%	37%	23%
Decarbonisation	37%	74%	28%	9%
CDR	14%	30%	2%	2%
SRM	7%	7%	2%	2%
Adaptation	--	--	--	61%

[1] Equal rankings were allowed: therefore columns may not add up to 100%.
[2] Adaptation was only included as an option for raising the HDI in 30 years.

Preferences are consistent with the estimated amount of political capital that experts would commit to a given response option, as reported in Figure 5.2. The expert sample, as a whole, is willing to expend the most personal effort on decarbonisation given the objective of reducing the rate of warming (median = 26%) but would commit more effort to adaptation given the objective of reducing short-term human vulnerability (median = 40%). Political capital investment on the two geoengineering options is generally low, but the wide variability in the estimates indicates a range of opinions across the expert group.

5.3.3 Response option portfolios

Experts were asked to consider a scenario whereby a 50% reduction in temperature was achieved on a socio-political timescale and describe how much each response option contributed to this outcome. This is a substantial reduction, given that to achieve the required reduction, a cut to cumulative emissions by almost half is necessary in 30 years, which - assuming a roughly linear trend - means ramping emissions down to nearly zero. This scenario is outside essentially all IPCC emission scenarios. About 70% of the experts relied on conservation, efficiency and decarbonisation to achieve at least three-quarters of the reduction.

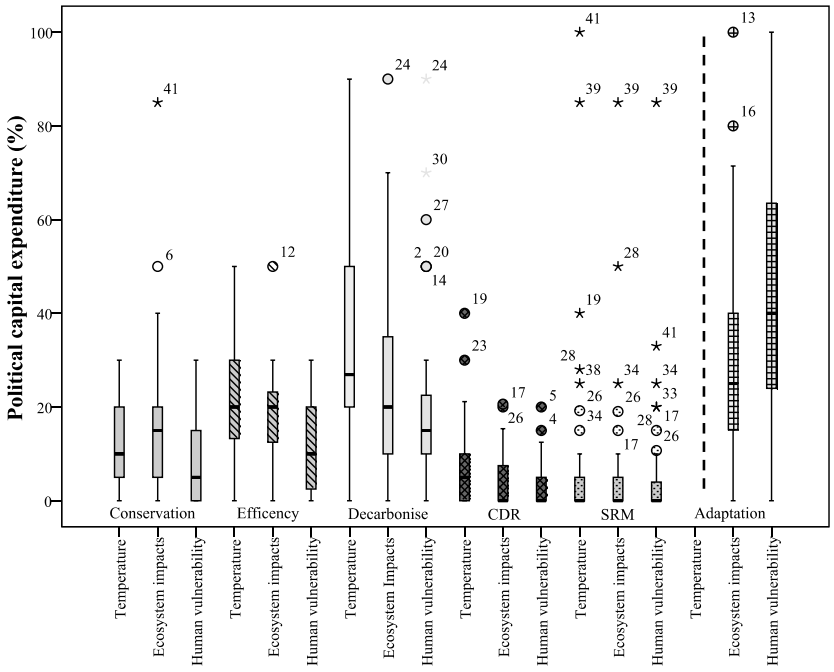


Figure 5.2 A box-plot summary of estimated political capital commitment across response options and climate strategy objective framing, on a socio-political timescale. The boxes cover the first to third quartiles estimates, with the sample median indicated. The circles identify outliers and asterisks specify extreme outliers. These outliers are labelled with the expert's number. *Temperature* refers to limiting global average temperature rise, *ecosystem impact* refers to reducing impacts on ecosystems caused by anthropogenic warming, and *human vulnerabilities* refers to reducing human vulnerabilities caused by anthropogenic warming. No measures were reported for expenditure of political capital on adaptation with the objective of limiting warming.

Consistent with their high preference, efficiency and decarbonisation, contributed on average 26% and 32% of the reduction, respectively. Individual portfolios are given in Figure 5.3.

Nineteen portfolios used some amount of SRM to achieve in their reduction portfolios, twelve of which included small contributions from SRM (under 10%). Four relied on SRM almost exclusively, achieving at least 80% of the overall temperature reduction from this response. The inclusion of SRM in these portfolios indicates a willingness, on the part of some experts, to consider its use. An independent mean comparison shows this consideration was characterized by differences in assessments of SRM and decarbonisation. Consistent with their position, experts considering SRM were significantly more willing to invest personal political capital into SRM, showed higher preferences for SRM across all objective framings and estimated SRM was more effective at limiting human and ecosystem damages. Experts were also characterized by a lower commitment of political capital to decarbonisation and estimated that it was less effective at emissions reductions (see Table 5.5). A willingness to consider SRM was not characterized by the type of expert (IPCC/invited) nor self-reported expertise. Interestingly, there are also no other effectiveness assessments of any other response options that differentiated this group.

5.3.4 Maximum effectiveness

The experts were asked to estimate the maximum effectiveness of each response option given a 0.5% commitment of global GDP. Individual estimates are indicated on Figure 5.4. There is no statistically significant difference in assessments by type of expert of self-reported expertise. Estimates of SRM's maximum effectiveness at reducing the temperature varied

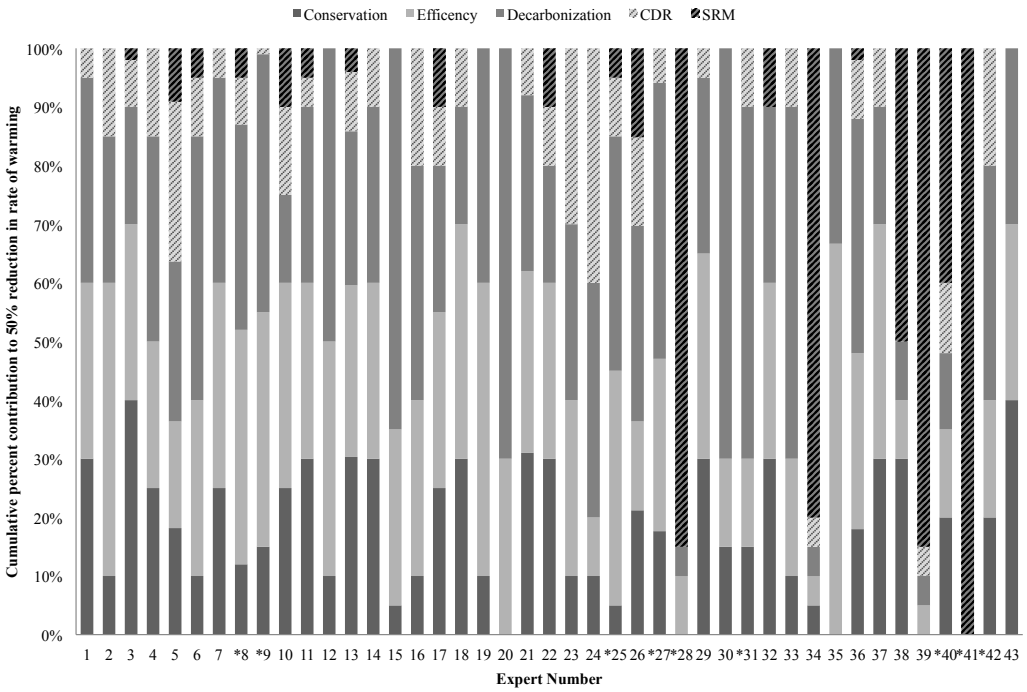


Figure 5.3 Individual expert portfolios measuring the percent contribution of each response option given the requirement of reducing the rate of warming by 50%. Asterisks beside expert numbers indicate invited experts.

Table 5.5 Mean comparisons of experts considering SRM and not considering SRM in their portfolios based on the discriminating measures

			No SRM consideration		**SRM consideration**		
Measure	*Response option*	*Objective*	*Mean*	*SD*	*Mean*	*SD*	
Political capital	Decarbonise	Limit global average temperature rise	37.3%	21.1	23.6%	19.6	**
	Decarbonise	Reduce human vulnerabilities	25.3%	23.9	13.1%	9.2	**
	Decarbonise	Reduce impacts on ecosystems	31.8%	23.8	17.2%	14.2	**
	SRM	Limit global average temperature rise	1.8%	8.2	16.7%	28.1	**
	SRM	Reduce impacts on ecosystems	0.4%	2.0	12.3%	21.5	**
	SRM	Reduce human vulnerabilities	1.3%	4.5	10.9%	20.4	*
Maximum possible reduction	Decarbonise	Limit net carbon emissions	42.1%	22.2	27.7%	18.0	**
	SRM	Reduce human vulnerabilities	23.6%	24.4	42.6%	31.4	*
	SRM	Reduce impacts on ecosystems	23.8%	24.0	42.2%	31.3	*

* p<0.1, ** p<0.05

across experts. At the median, experts estimate SRM could reduce temperature by 65%, fourteen of whom specify it could completely compensate for 100% of the temperature rise. Estimates are lower for possible reductions in ecosystem damage (median = 30%) and human vulnerability (median = 28%), reasons for which are explained in detail below. In contrast median estimates for temperature reduction of conservation, efficiency, decarbonisation and CDR, are all below 10%. This is calculated from estimates of the following average maximum emission reduction:

- conservation (M = 17%, SD = 12%);
- efficiency (M = 26%, SD = 14%);
- decarbonisation (M = 35%, SD = 21%) and
- CDR (M =13%, SD = 19%).[15]

SRM was not evaluated on this metric because it cannot alter the emissions rate. SRM is considered significantly more effective than the other response options at reducing the temperature ($p < 0.001$), but does not address the highest ranked objective of reducing long-term emissions.

The assessments of SRM's effectiveness raised concerns for some experts. One suggested, "I am aware that solar geoengineering is the most likely to accomplish a fast reduction in the average rate of warming, but considering all other issues, it remains my least preferred option" [E31]. Other experts refused outright to provide an estimate, stating that, "this

[15] These estimates were calculated based on the maximum possible reduction in emissions over 30 years give 0.5% of global GDP. Cumulative emissions and radiative forcing change roughly according to a logarithmic relationship. To convert emissions reductions to temperature change, it was assumed that a change in temperature was proportional to a radiative forcing. This simplifies some to the climatic dynamics, but on a 30 year timescale, these are small. The BAU scenario was assumed to be 2.1 ppm/yr for 30 years. The baseline for percent temperature change was calculated based on the pre-industrial atmospheric concentration (270 ppm).

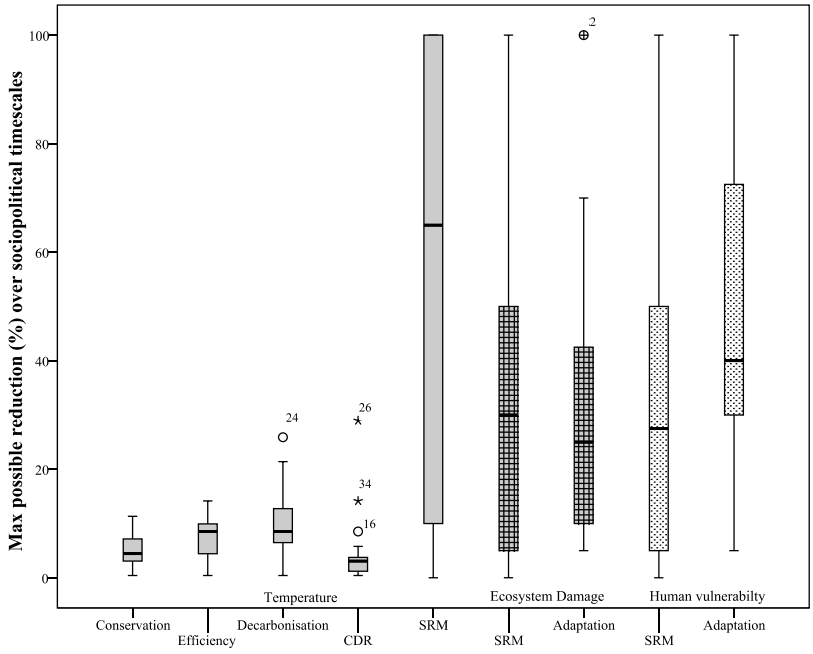


Figure 5.4 Box-plot summary of expert assessments of maximum potential change supposing (1) that 0.5% of the world's GDP was spent on the response option, and (2) that money was used as efficiently as possible. The boxes cover the first and third quartiles estimates, with the sample median indicated by the line. The circles indicate outliers and asterisks specify extreme outliers. These outliers are labelled with the providing expert's number. Eight experts were removed from this analysis because they saw a numerical error in the question. *Temperature* refers to limiting global average temperature rise, *ecosystem impact* refers to reducing impacts on ecosystems caused by anthropogenic warming, and *human vulnerabilities* refers to reducing human vulnerabilities caused by anthropogenic warming.

is not an acceptable strategy" [E12] and that "no assignation [was provided] due to the high risks' [E43]. Expert E1 did provide an assessment, but cautioned "You could theoretically prevent temperature increases, but there would be many negative consequences at the same time. Just because you could prevent temperature increases, does not mean that it should be done."

Discrepancies between the relatively high estimates of SRM's potential for temperature reductions and lower assessments for its potential to reduce ecosystem damage and human vulnerability were described in the additional textual comments. Experts highlighted the inability of SRM to avert ocean acidification impacts and other terrestrial impacts specifically related to

CO_2 [E25, 27]. Others questioned the feasibility of producing a stable aerosol cloud with the correct properties [E1], while a final group suggested that SRM does not address timing of certain thresholds being crossed [E31]. In regards to human vulnerability, expert's clarification of responses was more nuanced. They largely seemed to be related to the uncertain vulnerability that SRM may introduce into the human environment. E30 articulated this issue stating:

> I think the very substantial risk of us getting geoengineering wrong means that the likelihood of benefits and human vulnerability are probably less than zero. Given our inability to interact positively so far with the climate and earth systems generally, I think the idea that we might now try to manipulate these elements is fraught with risk associated with a lack of experience as an aside by a very bad track record so far.

In a similar tone, E2 cautioned that while,

> …the maximum possible reduction is a positive view, and it is high in my opinions, there is a minimum possible reduction [in human vulnerability] which is -100% because of a potential redistribution of the temperature anomaly on the planet.

Taken as a whole, these additional comments temper SRM's high effectiveness assessments, and provide some clarification to the variability in the assessments. They also point to a wider set of acceptability criteria by which judgments are being made.

5.3.5 Future climate

On average, experts agree that climate change will have catastrophic impacts on nature ($M = 6.0$, $SD = 1.4$) and humans ($M = 5.9$, $SD = 1.3$). Targets for atmospheric carbon concentration in 30 years ranged from 250 ppm to 550 ppm, with a median of 425 ppm, which is about a 50% reduction in the emission rate given continued linear growth. On a planetary timescale, target concentrations ranged from 180 ppm to 550 ppm, with the median matching the commonly proposed target of 350 ppm. Figure 5.5 summarizes individuals' bounded assessments of likely atmospheric carbon concentrations, given the political and economic realities of the climate problem on the socio-political timescale. The performance discrepancy between target and expected outcomes is on average 53 ppm ($SD = 52$ ppm). In general, this

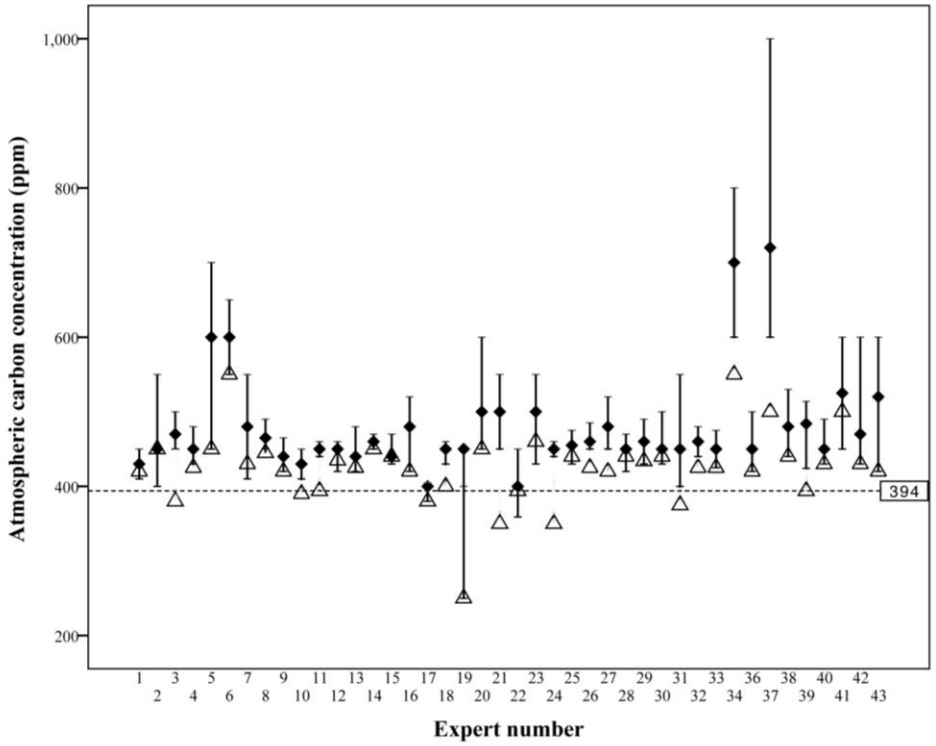


Figure 5.5 The performance discrepancy between likely and target atmospheric carbon concentrations in 30 years by expert. The triangle denotes target atmospheric carbon concentration. The diamond indicate the likely concentration estimate in 30 years bounded by the 10th and 90th percentile estimates. The 394 ppm reference line was the average annual atmospheric carbon concentration in 2012, given to each expert in the survey.

would suggest that experts would like to see a large change in the next 30 years, but think it unlikely.

5.4 Discussion

There was strong agreement amongst the experts that more established climate response options including decarbonisation and efficiency were preferred in the short-term. This is despite poor perceptions of its maximum effectiveness at limiting temperature change. But given the importance placed on reducing long-term GHG emissions, the preferences for efficiency and decarbonisation are consistent, especially on the planetary timescale. Preference for, and use of,

SRM were almost universally low, despite assessments that it was more (if not completely in some estimates) effective at limiting temperature increase and reducing human vulnerabilities and ecosystem damage. This discrepancy suggests that the acceptability of SRM, for some, is being driven by criteria other than its own perceived effectiveness.

Not surprisingly, a feature of experts' willingness to consider SRM is a higher perceived effectiveness of its ability to limit human vulnerability and ecosystem damage, or in other words a higher perception of its maximum benefits. Consistent with past research on emerging technologies, higher perceived benefits are important to positive perceptions of acceptability. This group also estimated decarbonisation is 15% less effective at reducing emissions than the other experts in the sample. This criterion, the perceived effectiveness of the other response options, is only significant for decarbonisation. One explanation may be that as experts become increasingly pessimistic about mitigation, the more willing they are to consider SRM. Anecdotally, this has been one justification used for pursuing and researching SRM.

The median 30-year target atmospheric carbon concentration calls for about a 50% reduction to the rate of emissions compared to a linear BAU-scenario. Given the expert's preferred approach - a major portion of this reduction coming from efficiency and decarbonisation - the combined average maximum possible carbon emission reductions is about 60% (assuming all efforts are additive). A 30-year target that would see atmospheric concentrations below 400 ppm is proposed by 26% of the experts, which essentially calls for zero emissions. Carbon-based responses alone, each deployed at their average estimated maximum potential suggest this magnitude of reduction is unattainable. Any carbon based strategy that allows for large temperature reductions will cost multiple percent of GDP. SRM could obtain those reductions with considerably less investment. Not prioritizing cost

effectiveness, is consistent with the low importance assigned by experts to limiting the cost of a climate strategy.

Concerns relating to the socio-political timescale were levelled by some experts as too short for considering significant mitigation, which problematically biased their results towards over-selection of SRM. This is further supported by experts' average maximum effectiveness estimate showing that the given 50% temperature reduction was not attainable in this timeframe. This scenario was intentionally designed to limit considerations to a decision context that provided a reasonable scenario where SRM may be considered. The results and additional comments suggest that a slightly longer framing, potentially more in line with major infrastructure turnover rates (50-60 years), may have resulted in changes in maximum potential assessment and an increased use of carbon methods. This would suggest that the response option portfolios should be viewed as providing high SRM-use estimates. Even considering this bias towards SRM, only about half of the experts considered it in their portfolios, suggesting low overall acceptability.

Consistent with past research in this area, there was significantly more variance across assessments and judgments of SRM than other response options. This shows a wide range of opinions about this new technology in the expert community. Experts expressed higher levels of uncertainty in the textual comments about SRM related-responses. This is not surprising, even in an informed population, as scientific research remains ongoing. Some of the experts raised significant concerns about the acceptability of SRM, including outright rejection of the technology. This unacceptability is likely driven by criteria that were not tested for in this study. Bellamy *et al.* (2013) observed SRM rejection when the following criteria were seen as

unacceptable: social acceptability, socioeconomic impacts, governance, political acceptability, distributive justice, and ownership and control.

The internet-based expert survey method allowed for access to a larger sample of experts with a vast geographical distribution. This was the basis for the choice of this approach. As such, this study includes opinions from experts from geographical areas that are under-represented in the geoengineering literature. The difficulty with this approach is the challenge of collecting deeply contextualized opinions characteristic of an expert. While the use of the additional comment feature was extensive, it did not allow for the same depth of follow-up questions that an in-person methodology would have afforded. For example, the two experts who refused to provide effectiveness assessments for SRM suggested that this technology was not acceptable. An in-person method would have allowed for clarification of the criteria by which this judgment was made. Bellamey *et al.* (2013) used a computer platform with an interviewer present to address this concern. Similar research may benefit from some inclusion of this mixed method.

This research shows that there is a strong overall preference for efficiency, decarbonisation and conservation, as well as adaptation given a human vulnerability objective. Experts would prefer to use mitigation and efficiency, which, given a commitment of 0.5% of GDP to either would reduce emissions by about 30%. This would results in a small overall change in temperature (under 10%). Achieving the deep emissions cuts specified in some experts' target atmospheric concentrations would require a substantial proportion of GDP beyond the 0.5% commitment. SRM is the least-preferred option, and for some, totally unacceptable, however it is estimated to be able to reduce the overall temperature rise by a median of 65%. Those who would consider its use, see it as better able to reduce ecosystem and human vulnerabilities, and decarbonisation as being less effective at emissions control. In

general, experts see emissions management as the utmost importance while proposing concentration targets and limiting financial costs as the least important. The preferences for efficiency, conservation and decarbonisation are consistent with their objective preferences.

5.5 Chapter Summary

Considerations of SRM in traditional climate forums, such as the IPCC, signify a shift in the scientific communities towards an increased acceptance of this response. This research suggests, however, that this shift should not be understood as SRM being widely perceived as an acceptable technology. Rather, it remains a low preferred climate response with criteria, other than maximum effectiveness, influencing this preference. Criteria identified in this research are: perceived benefits of SRM and estimates of decarbonisation's ability to effectively lower emissions. Additional comments from experts suggest that the extent of potential risks may also be a criterion that is being considered in judgments of SRM.

CHAPTER 6: CONCLUSION

6.1 Introduction

Solar radiation management has increasingly become a response option being considered as one component of a broader strategy to limit unwanted anthropogenic climate change. Intervention and control of the climate is very controversial, across public and expert populations. Studying the attitudes and opinions of the relevant stakeholders at this early stage provides empirical evidence to inform the broader climate policy decisions we face.

This dissertation set out to: investigate factors that may contribute to lay people's perceptions of SRM's acceptability; and explore expert judgments about SRM in the context of a broader climate strategy. As such, I have presented two studies that were designed to address these objectives. The public survey, described in Chapter 4, outlines the emerging supporter and detractor positions, along with some common non-scientific tensions that are raised during deliberation of SRM. The expert survey, presented in Chapter 5, shows that perceptions of SRM effectiveness were not the dominant criterion but perceptions of its maximum benefits characterized experts' willingness to consider its use.

This chapter serves as an overall summary of the thesis, and as such, it draws conclusions from both studies and presents the overall findings about technological acceptability of SRM. The chapter starts by summarising nine criteria for SRM's acceptability. It also provides suggestions for further studies and a final reflection on researching SRM.

6.2 Acceptability of SRM

Broadly speaking, this dissertation confirms the expectation that people *can* meaningfully

consider and contribute to discussions of SRM. Responses to the public survey, both closed-ended and open-ended, show that individuals were willing to actively engage and consider SRM. This thesis contributes empirical evidence identifying some of non-technical criteria that may influence conditional acceptability of SRM. Many of these results are characteristic of opinions on emerging technologies and align with findings from past research. The following is a summary of identified acceptability criteria.

6.2.1 Perceived effectiveness of mitigation

Experts who considered SRM use, evaluated mitigation as being significantly less effective at reducing the temperature rise than experts who rely solely on carbon-based responses. As such, the perceived effectiveness of mitigation may be an important criterion in considering SRM's acceptability. This criterion is supported by the emerging narratives in the literature justifying expert consideration of SRM.

6.2.2 Extent and quality of the intervention

Individuals distinguished between the level of SRM activity, e.g. research, emergency deployment and full-scale use. Public participants consistently show significantly different attitudes towards research activities and deployment. A criterion of acceptability may consider the extent and quality of the intervention into the earth system.

6.2.3 Level of Trust

Higher levels of trust were found to be a predictor of support of SRM and, as such, a criterion for acceptability. The importance of trust is strongly supported by past research on other emerging technologies.

6.2.4 Perceived benefits

Experts who perceived SRM as better able to reduce human vulnerabilities and

ecosystem damage were more likely to consider its use. In the public survey, support was predicted based on a higher perceived benefit of SRM. The importance of this acceptability criterion for emerging technologies is supported by past research.

6.2.5 Perceived risks

Perceived risks of a technology have been shown to be an important criterion for technological acceptability. The public survey supports this finding, as it shows risks are universally important in opinion formation. Experts also justified their responses (or lack thereof) based on high perceived risk, which is likely to negatively affect acceptability.

6.2.6 Perceived naturalness

Consistent with other research on SRM perceptions, the perceived 'naturalness' of the intervention was found to be a predictor of SRM support. An in-depth analysis by Corner *et al*. (2013) has suggested that this criterion has numerous facets, but in general is an important predictor of acceptability. Perceptions of unnatural interventions negatively influence acceptability.

6.2.7 Perceived control

Participants were concerned about technological control of SRM. While this research did not quantitatively measure this criterion, it arose in the quantitative analysis of the survey. One could extrapolate from risk research that a perception of low controllability (either technically and/or governance) of SRM will lead to higher perceived risk and lower acceptability.

6.2.8 Perceived uncertainty

Participants also identified uncertainty and knowledge limitations as a concern of SRM. Other researchers have observed similar concerns. While not specifically measured in the study,

it is likely that high perceptions of uncertainty in the science and the impacts associated with SRM will lead to low acceptability.

6.2.9 Perceived climate threat

While this thesis did not find evidence of climate opinions affecting acceptability assessments in the expert or public populations, other researchers have. It is possible that our tests were not sensitive enough to identify a relationship. It is also possible that this is a weak criterion for consideration. Future research should clarify this issue.

Despite the potential for conditional acceptability, based on the above criteria, there was also a component of both the public and expert groups that considered SRM as unacceptable. Within the expert sample, there was a group that refused to provide effectiveness assessments with one expert suggesting that the risks were too high. In the lay population this opposition position (detractor) was predicted by the ideological position that humans should not be interfering with nature. Given an ideological opposition, it is unlikely that future research will make SRM more acceptable, as it will always involve directly intervening in natural processes.

Opinions and attitudes in both expert and public groups are likely to shift and change. It is reasonable to assume that as the science advances and there is a better understanding of SRM, that some people, especially in the expert community, will shift their opinions and attitudes to reflect these advances. It is also likely that events, particularly salient ones like a crisis, linked to climate change and/or geoengineering will influence opinions of SRM.

Taken as a whole, this research reinforces the observation that there is not a single uniform public or climate expert opinion or judgment of SRM. Indeed there are a range of opinions being made on a wider set of criteria than cost effectiveness, and as such, policy discussions on SRM must include analysis on a range of criteria to ensure that the breadth of

acceptability criteria are included.

6.3 Contributions to knowledge

This is the first PhD thesis to address acceptability criteria for SRM using empirical social science methods. It provides evidence to support the early hypothesis of the importance of social, political and ethical criteria in judgments about SRM and identifies a set of criteria that are relevant to its future consideration. This thesis contributes support to early emerging technology perception research on the importance of certain criteria in early technical judgments. Finally, this thesis expands the understanding of how individuals make judgments about SRM.

6.4 Future Areas of Study

Over the four and a half years of my research, I have seen an incredible growth in discussion of geoengineering. Published just months before the start of my doctoral studies, Victor *et al.* (2009: 73) characterized the research community as very small, stating "nearly the entire community of geoengineering scientists could fit comfortably in a single university seminar room, and the entire scientific literature on the subject could be read during the course of a transatlantic flight." Since then, the geoengineering research community has grown substantially, as has SRM's public visibility. Currently, there are multiple research groups running various studies to understand the science behind SRM and specific aspects of peoples' attitudes and perceptions. My work and my thinking have evolved over the course of this thesis, from initially setting out to characterize emerging attitudes about SRM, to exploring the trade-offs that we face in the greater decision context. The following suggestions for future studies represent an important continuation of this development.

6.4.1 Future technological acceptability research

One of the most interesting questions that emerged from the survey results related to the way in which environmentalists, conservatives and climate sceptics may be divided on support for SRM. There is preliminary evidence suggesting that support for SRM may be drawn along different lines than climate mitigation. Further examination at both a statistical and more detailed interview level is necessary to understand how this support cuts across classic demographic groupings of opinions around climate change. This may have important policy implications for understanding how trade-offs between mitigation strategies and SRM conflict.

The public survey in this thesis is a baseline assessment of attitudes. Continuing to track opinions over time may provide important insight to the changes taking place over the research and development of this technology (if that is indeed SRM's development trajectory). Given a continued progression of SRM development, a future research project that proposes some form of stratospheric injection (however limited) would provide an important opportunity to ground perception research in a specific decision context. Work by Pidgeon *et al.* (2013) about the proposed SPICE project in the UK provides an example of this value. Basing research on the technical acceptability of a specific imminent proposal provides a tangible scenario where participants can be grounded in real-world implications.

6.4.2 Future study with trade-off decisions

The expert survey selected participants based on climate change expertise, which resulted in low variance across the preference functions. A follow-up study with experts who have expressed a strong positive or negative position on SRM would provide additional insight into the criteria that are influencing these more extreme positions.

As mentioned in Chapter 5, another avenue of study would be to use the current online survey tool in an in-person interview setting. This would have the advantage of discussing the preferences and use portfolios with the experts and gaining deeper insight into some of their acceptability criteria.

6.4.3 Social science SRM research into the future

Studies about SRM have largely taken place in developed, technologically advanced nations. Other geographic regions not currently represented, such as African nations, are known to have differing environmental and technical values and different perceptions of non-scientific tensions. They are also affected differently by the regional impacts of climate change and SRM. Since SRM has global implications, understanding different judgments from a variety of perspectives, notably developing nations, is very important. Research must be thoughtfully expanded to different groups of individuals, specifically those underrepresented in the current research.

6.5 A final reflection

As I conclude, I want to leave you with my final reflections on studying SRM. I feel it is important for you, as a reader, to understand the deep conflicts that this work raises for me. Studying it is uncomfortable, worrying and sometimes upsetting. Listening and analyzing the range of opinions has given me great insight into the concern that this technology evokes in people. I have struggled throughout my research to grasp the enormity of intervening in the environment, with its uncountable species, each having different needs. Studying SRM is not something I undertook lightly, nor without constant reflection. While I have spent four and a half years immersed in SRM research, my deepest and most sincere hope is that we are able to find a way to transition into a world where we do not need it, ultimately making much of this thesis

unimportant. The world as it is today, however, is considering SRM because we are facing some potentially catastrophic impacts on human and natural systems from the anthropogenic-caused changes to our climate. So long as SRM is being considered by some, I have come to believe that providing spaces for people to contemplate, engage and be heard in discussions pertaining to SRM is vital. The choices about SRM are ultimately decisions with global consequences, which will redefine our relationship with the Earth. Open, thoughtful, inclusive and respectful dialogue must continue to dominate.

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APPENDIX A – LAY SURVEY TOOL

1A. Have you ever heard of geoengineering?
[Yes/No/Unsure]

1B. What do you think geoengineering is?
[Open]

2A. Have you ever heard of climate engineering?
[Yes/No/Unsure]

2B. What do you think climate engineering is?
[Open]

[Put all of question 3 on one page]

Some people have suggested that it is possible to cool the planet without changing how much fossil fuel (like coal and oil) we use.

3A. How familiar are you with this idea?
[Not at all familiar, a little familiar, somewhat familiar, very familiar, I am unsure.]

3B. Do you believe it is true that you can cool the planet without changing how much fossil fuel we use?
[4 point scale: Completely false, somewhat false, somewhat true, completely true, I am unsure]

3C. Do you believe we should cool the planet without changing how much fossil fuel we use?
[4 point scale: strongly disagree, somewhat disagree, somewhat agree, strongly agree, I am unsure]

[Put all of question 4 on one page]

Some people think it is possible to cool the planet by spraying the sky with a chemical that blocks sunlight.

4A. How familiar are you with this idea?
[Not at all familiar, a little familiar, somewhat familiar, very familiar, I am unsure.]

4B. Do you believe it is true that you can cool the planet by spraying the sky with a chemical that blocks sunlight?
[4 point scale: completely false, somewhat false, somewhat true, completely true, I am unsure]

4C. Do you believe we should cool the planet by spraying the sky with a chemical that blocks sunlight?
[4 point scale: strongly disagree, somewhat disagree, somewhat agree, strongly agree, I am unsure]

5. Do you think that geoengineering should be used as a solution to global warming?
[4 point scale: strongly disagree, somewhat disagree, somewhat agree, strongly agree, I am unsure]

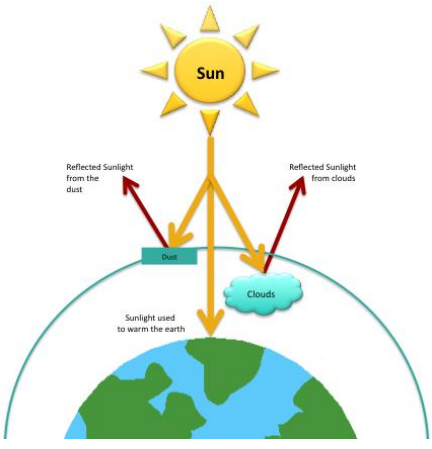
6. What is your opinion about each of the following statements?
[5 point scale: strongly disagree, disagree, neutral, agree, strongly agree, plus I am unsure]
   a. Global warming is a serious problem.
   b. Humans are primarily responsible for global warming.
   c. One person's actions have no impact on global warming.
   d. My government should do more to deal with global warming.

7. What is your opinion about each of the following statements?
[*4 point scale: strongly disagree to strongly agree, plus I am unsure*]
[Randomize order]
   a. People have done a good job using technology to fix environmental problems.
   b. Humans know enough about how nature works to be able to control it.
   c. We must develop new technologies to solve global warming.
   d. I worry that people expect technology will fix the changing climate.
   e. Technologies that work like nature are best.

The following information about SRM will be provided to respondents before proceeding with the survey. In order to avoid overwhelming respondents, the information should be split across a number of screens with only a limited amount of information on each screen. Each subsequent survey page should have a link that respondents can click in order to see the SRM information again. ("Click here to see the information about Solar Radiation Management again").

On the next ***5*** screens, you will read about the sun, the Earth's temperature and Solar Radiation Management. Please read all the information, as it will help you with the rest of the survey.

How the sun heats the earth



- Sunlight warms the Earth and its atmosphere (the air and other gases surrounding the Earth).
- When the sun's rays get to the atmosphere, some are reflected by the clouds and dust in the atmosphere. These rays do not heat the earth.
- The rest of the sun's rays heat the earth's surface. Gases in the atmosphere (such as carbon dioxide) trap the heat near the earth. This makes the earth warm enough for humans, animals and plants to live.
- If less sunlight reached the earth, less heat would be trapped and the earth's climate would get cooler.

Problems with the Earth's rising temperature

- Burning fossil fuels like coal, oil and natural gas puts more greenhouse (heat-trapping) gases into the atmosphere. These are called emissions.
- The extra gases trap more heat and make the Earth's temperature warmer.
- Greenhouse gases last in the atmosphere for a very long time (more than a century). So, even if we cut emissions quickly, gases released in the past will cause the earth's temperature to

rise.

- Higher temperatures change the Earth by:
    - Making rain and snow fall less;
    - Making ice and glaciers melt faster;
    - Making ocean levels higher, changing coastlines and hurting coastal cities; and
    - Making dangerous storms like hurricanes, tornados and snow storms stronger.
- Many scientists think that at some point the Earth's temperature will get too warm. This might cause a "climate emergency" that leads to:
    - Serious heat waves that threaten the health of the elderly and ill;
    - Severe droughts that destroy farm crops across large areas in Africa or North America; and
    - The ocean rising and flooding a major coastal city (like New York City).

Solar Radiation Management

- Solar Radiation Management is a possible way to lower the earth's temperature.
- Solar Radiation Management is a type of geoengineering.
- To stop some of the sun's rays, a substance (such as small sulfur particles) would be sprayed into the atmosphere. This substance forms a kind of fine dust that reflects sunlight back into space before it can warm the earth.
- Some scientists think this idea will work because a similar thing happens in nature. When big volcanoes erupt, they spray the same chemical into the atmosphere, and the earth cools.

[RANDOMIZE ORDER and bullet points of BENEFITS AND PROBLEMS]

Some Benefits of Solar Radiation Management

- The expected benefits of Solar Radiation Management are that it will:
    1. Slow global warming and reduce its dangerous impacts, giving us more time to cut greenhouse gas emissions;
    2. Slow or stop global warming quicker than is possible by cutting emissions;
    3. Be the only way to manage the risk of rising temperatures (caused by long lasting greenhouse gases) during this century;
    4. Stop a climate emergency before too much damage is done; and
    5. Be much cheaper than stopping our use of fuels that release greenhouse gases.

Some Problems with Solar Radiation Management

- The expected problems with Solar Radiation Management are that it will:
    1. Change how much it rains in some parts of the world;
    2. Damage the ozone layer;
    3. Take away people's motivation to change their current lifestyle and stop using coal, oil and natural gas;
    4. Allow coal, oil and natural gas companies to keep releasing greenhouse gases into the atmosphere; and
    5. Potentially cause something to happen that we can't predict.

[to go as the last point after problems or benefits]

- Scientists believe that studying Solar Radiation Management on a small scale for the next several years will help them to better understand the possible risks and benefits of this

technology.

8A. Do you feel that the information you just read was clear?

a. It was completely clear
b. It was somewhat clear
c. It was somewhat unclear
d. It was completely unclear

8B. Do you feel that the information you just read had a bias?

a. It was supportive of Solar Radiation Management.
b. It was neutral, and did not support or oppose Solar Radiation Management.
c. It was opposed to Solar Radiation Management.

9. Do you think that geoengineering should be used as a solution to global warming?
[4 point scale: strongly disagree, somewhat disagree, somewhat agree, strongly agree, I am unsure]

10. Do you think scientists should study Solar Radiation Management?
[*4 point scale – strongly oppose to strongly support, or I am unsure*]

11. What do you think about using Solar Radiation Management to stop a climate emergency?
[*4 point scale – strongly oppose to strongly support, or I am unsure*]

12. If Solar Radiation Management was possible today, what would you think about using it immediately?
[*4 point scale – strongly oppose to strongly support, or I am unsure*]

13. Do you think that Solar Radiation Management should never be used, no matter the situation?
[*4 point scale – strongly disagree to strongly agree, or I am unsure*]

14. Earlier, you read about some of the potential benefits and risks of Solar Radiation Management. Please rate the importance of each of the following risks and benefits <u>to you in forming your opinion</u> about Solar Radiation Management?
Note: If you would like to read the information about Solar Radiation Management again, please click here.
[*Not at all Important, somewhat unimportant, somewhat important, very important]*
*[***RANDOMIZE***]*

1. It will slow global warming and reduce its dangerous impacts, giving us more time to cut greenhouse gas emissions.
2. It will slow or stop global warming quicker than is possible by cutting emissions.
3. It is the only way to manage the risk of rising temperatures (caused by long lasting greenhouse gases) during this century.
4. It will stop a climate emergency before too much damage is done.

5. It will be much cheaper than stopping our use of fuels that release greenhouse gases.
6. It will change how much it rains in some parts of the world.
7. It will damage the ozone layer.
8. It will take away people's motivation to change their current lifestyle and stop using coal, oil and natural gas.
9. It will allow coal, oil and natural gas companies to keep releasing greenhouse gases into the atmosphere.
10. It will potentially cause something to happen that we can't predict.

15. What is your opinion about each of the following statements?
[4-point scale – totally disagree to totally agree, and I am unsure] **[RANDOMIZE]**
    a. Solar Radiation Management will help the planet more than it will hurt it.
    b. With enough research, I believe Solar Radiation Management will turn out to be safe and effective.
    c. Solar Radiation Management should be used so we can continue to use oil, coal and natural gas.
    d. Solar Radiation Management is the easy way out.
    e. Research into Solar Radiation Management will lead to a technology that will be used no matter what the public thinks.
    f. The earth's temperature is too complicated to fix with one technology.
    g. Humans should not be manipulating nature in this way.
    h. Solar Radiation Management is natural.
    i. If scientists find that Solar Radiation Management can reduce the impacts of global warming with minimal side-effects, then I would support its use.

16. How much would you trust information about Solar Radiation Management from each of the following groups?
[4-point scale - Would not trust at all, somewhat distrust, somewhat trust, completely trust]
[RANDOMIZE]
    a. Federal government
    b. Private companies developing Solar Radiation Management projects
    c. Environmental organizations
    d. University researchers studying Solar Radiation Management
    e. Industries that might benefit from Solar Radiation Management
    f. Media and reporters
    g. United Nations
    h. Religious leaders
    i. Family and friends

17. If you had the chance to talk to Solar Radiation Management researchers and decision makers, what would you say or ask?
[Open]

18A. Some people think the government has a secret program that uses airplanes to put harmful chemicals into the air (often called chemtrails).
How familiar are you with this idea?
[Not at all familiar, a little familiar, somewhat familiar, very familiar, I am unsure.]
Do you believe it is true that the government has a secret program that uses airplanes to put harmful chemicals into the air?
[4 point scale: Completely false, somewhat false, somewhat true, completely true, I am unsure]

[*If for 18A: somewhat true to true*]
18B. Why do you think the government is doing this?
[Open]

Demographics
(To be provided by Knowledge Networks, with corresponding questions added to the GMI surveys)
Age
Education level
Gender
Location (State/province/region etc)

Please indicate your religion
1. Buddhism
2. Christianity
3. Hinduism
4. Islam
5. Judaism
6. Sikhism
7. Non-religious (secular, agnostic, atheist)
8. Other (Please specify)
9. Prefer not to answer

Political affiliation/leaning

How would you describe your political views?
[1= very conservative; 2=conservative; 3=moderate (middle of the road); 4=liberal; 5=very liberal]

In elections, I normally vote for the:

Canadian survey [1=Bloc Quebecois; 2=Conservative Party of Canada; 3=Green Party of Canada; 4=Liberal Party of Canada; 5=New Democratic Party; 6=Other; 7=Prefer not to Answer] [RANDOMIZE except 6 and 7]

American Survey [1=Democratic Party; 2=Republican Party; 3=Other, 4=Prefer not to Answer] [RANDOMIZE except 3 and 4]

UK Survey [1=Conservative Party; 2=Labour Party; 3=Liberal Democrats; 5=Other, 6=Prefer not to Answer] [RANDOMIZE except 5 and 6]

APPENDIX B – EXPERT SURVEY TOOL

An example of each the: 1) card sort; 2) allocation allotment; 3) slider tool; 4) multiple choice tool; and 5) open response tool will be given at the end of the Appendix.

SURVEY TEXT:

Info 1 In this survey we will ask you to consider two different timescales: *30 years* and *300 years*.

30 years is what we term a plausible **sociopolitical timescale**. It should be thought of as a period over which our current political and social decisions may directly impact large-scale policies and investment decisions.

300 years is what we term a **planetary timescale**. It should be thought of as the period of time where some of the most important geophysical processes related to climate change, such as changes in carbon dioxide concentration, and the response of the ocean and cryosphere will occur.

Info 2 In this survey we will ask your opinion about a hypothetical **global climate strategy.** This should be thought of as the approach you believe would be best for managing climate change and its impacts. Action include conservation, efficiency, decarbonizing energy supply, carbon geoengineering, solar geoengineering, and adaptation.

Info 3 Throughout the survey, the **"Qualify your answer"** button (on the right of the page), gives you the chance to provide further information or comment. You will not be required to qualify any answer, but feel free at any time to use this feature for an answer you feel requires further explanation.

Q1_A Imagine you are given the authority to design a global climate strategy over the next 30 years to address anthropogenic climate change.

In your own words, what should be the overarching goal(s) of the strategy? *[open response]*

Q1_B Imagine you are given the authority to design a global climate strategy over the next 300 years to address anthropogenic climate change.

In your own words, what should be the overarching goal(s) of the strategy? *[open response]*

Q1_C What are your reasons for wanting to limit climate change?

We are **not** looking for the amount that you think emission should be reduced, or

other specific ways that climate risks should be mitigated but rather **we want** the objectives/goals/motivations that should, in your view, be the reason to undertake specific actions to limit climate change.
[open response]

Q2_A Climate strategy could focus on a variety of objectives. This list of objectives was derived from a set of structured interviews with a small group of experts.

Please rate the importance to you of each of the following objective for a climate strategy over the next 30 years.
[Not at all important; Low importance; Slightly important; Neutral; Moderately important; Very important; Extremely important]
[Randomize order]

1. Limit the overall financial costs of the climate strategy
2. Promote broad stakeholder participation in climate related decisions
3. Enhance people's ability to adapt to climate change
4. Limit disruption to natural environments (e.g., species extinctions)
5. Limit novel risks introduced by components of the planned strategy
6. Limit the impact of climate change on the most vulnerable people
7. Limit any future emissions of long lived greenhouse gases (e.g., CO_2, SF_6)
8. Ensure the full range of climate impacts are addressed
9. Limit negative impacts on human infrastructure (e.g., coastal infrastructure and irrigation systems)
10. Limit loss of ecosystem services (e.g., waste decomposition, surge protection and crop pollination)
11. Ensure equitable sharing of the climate change burden between rich and poor countries
12. Limit negative impacts on future generations
13. Limit any future emissions of short lived greenhouse gases (e.g., black carbon, CH_4)

Q2_B Climate strategy could focus on a variety of objectives. This list of objectives was derived from a set of structured interviews with a small group of experts.

Please rate the importance to you of each of the following objective for a climate strategy over the next 300 years.
[Not at all important; Low importance; Slightly important; Neutral; Moderately important; Very important; Extremely important]
[Randomize order]

1. Limit the overall financial costs of the climate strategy
2. Promote broad stakeholder participation in climate related decisions
3. Enhance people's ability to adapt to climate change
4. Limit disruption to natural environments (e.g., species extinctions)
5. Limit novel risks introduced by components of the planned strategy

6. Limit the impact of climate change on the most vulnerable people
7. Limit any future emissions of long lived greenhouse gases (e.g., CO_2, SF_6)
8. Ensure the full range of climate impacts are addressed
9. Limit negative impacts on human infrastructure (e.g., coastal infrastructure and irrigation systems)
10. Limit loss of ecosystem services (e.g., waste decomposition, surge protection and crop pollination)
11. Ensure equitable sharing of the climate change burden between rich and poor countries
12. Limit negative impacts on future generations
13. Limit any future emissions of short lived greenhouse gases (e.g., black carbon, CH_4)

Response options

The following table shows the comprehensive range of actions available for addressing climate change. These broad categories of actions include many different techniques on various spatial and temporal scales. The rest of the survey will ask you to make comparisons and consider trade-off between these actions. Please familiarize yourself with these definitions.

See Table 1.1 in Chapter 1 of the thesis

Q3_A1

Assume you are charged with reducing the average rate of warming over the next 30 years by a factor of two (i.e., a 50% reduction) relative to your best business-as-usual forecast.

Please rank, in order of your preference, the following actions from the most preferred to least preferred for reducing the rate warming by a factor of two (equal rankings are allowed).

Card sort most preferred to least preferred
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering]

Q3_A2

Assuming your strategy achieved the required reduction in rate of warming over the next, how much did each action contributed to temperature reduction? We are looking for the fraction of total reduction achieved by each action if it had acted alone.

Allocation allotment: Percentage used
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering]

Q3_B

Now, assume you are charged with holding temperature rise to no more than 2 degrees Celsius in 300 years time.

Please rank, in order of your preference, the following actions from the most preferred to least preferred action to hold temperature rise to no more than 2 degrees Celsius in 300 years time (equal rankings are allowed).

Card sort most preferred to least preferred
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering]

Q3_C1 The Millennium Ecosystem Assessment estimates that 20% of all species are believed to be threatened with extinction in the near future, and rates of biodiversity loss over various biomes are "substantial and predominantly negative."

Assume you are charged with lowering the rate of biodiversity loss in time. What fraction of total available resources for biodiversity loss would you commit to addressing climate change compared to other areas of potential interventions (e.g., land-use and habitat management, invasive species management, pollution control)?

Slider tool
[Climate change/other interventions]

Q3_C2 Please rank, in order of importance, the following actions you see as the most important for lowering the rate of biodiversity loss in 30 years (equal rankings are allowed).

Card sort: most preferred to least preferred
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering]

Q3_D1 The Human Development Index is a comparative measure of life expectancy, education, and income for countries worldwide. In 2012, Niger's was indexed at 0.304 and in comparison, the USA was 0.937.

Assume you are charged with raising the Human Development Index of Niger in 30 years time. What fraction of total available poverty alleviation resources would you commit to addressing climate change compared to other areas of intervention (e.g., maternal health, primary school education, disaster relief funding)?

Slider tool
[Climate change/other interventions]

Q3_D2 Please rank, in order of importance, the following actions you see as the most important for raising the Human Development Index of Niger in 30 years (equal rankings are allowed).

Card sort: most preferred to least preferred
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering, Adaptation]

Q4_A We are now interested in your opinion of how you would prioritize your efforts to advocate for various climate measures. Imagine you are given 100 'effort points', where each point equals one unit of effort dedicated to advocating for policies aimed at addressing climate change. Your total effort could be considered your maximum political capital.

How much effort would you expend on 'lobbying' policymakers to implement each measure with the goal of limiting global average temperature rise over 30 years? Please assign your 100 effort points below to the actions.
By 'lobbying' we mean spending political capital to make things happen by whatever means you judge most appropriate which may or may not include formal lobbying. For example, if you believe measure X will take much more effort than measure Y, you might assign most of your effort point to measure X, effectively saying you would spend more of your time 'lobbying' for measure X because it will be harder to achieve politically.

Allocation allotment: Effort points
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering]

Q4_B We are now interested in your opinion of how you would prioritize your efforts to advocate for various climate measures. Imagine you are given 100 'effort points', where each point equals one unit of effort dedicated to advocating for policies aimed at addressing climate change. Your total effort could be considered your maximum political capital.

How much effort would you expend on 'lobbying' policymakers to implement each options with the goal of reducing impacts on ecosystems caused by anthropogenic warming over 30 years?

Please assign your 100 effort points below to the actions.
By 'lobbying' we mean spending political capital to make things happen by whatever means you judge most appropriate which may or may not include formal lobbying. For example, if you believe measure X will take much more effort than measure Y, you might assign most of your effort point to measure X, effectively saying you would spend more of your time 'lobbying' for measure X because it will be harder to achieve politically.

Allocation allotment: Effort points
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering, Adaptation]

Q4_C We are now interested in your opinion of how you would prioritize your efforts to advocate for various climate measures. Imagine you are given 100 'effort points', where each point equals one unit of effort dedicated to advocating for policies aimed at addressing climate change. Your total effort could be considered your maximum political capital.

How much effort would you expend on 'lobbying' policymakers to implement each options with the goal of reducing human vulnerabilities caused by anthropogenic warming over 30 years?

Please assign your 100 effort points below to the actions.
By 'lobbying' we mean spending political capital to make things happen by whatever means you judge most appropriate which may or may not include formal lobbying. For example, if you believe measure X will take much more effort than measure Y, you might assign most of your effort point to measure X, effectively saying you would spend more of your time 'lobbying' for measure X because it will be harder to achieve politically.

Allocation allotment: Effort points
[Conservation, Efficiency, Decarbonization, Carbon geoengineering, Solar geoengineering, Adaptation]

Q5_A Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on conservation, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.

If you were to allocate all of this money to conservation what would be the maximum possible percent reduction in net carbon emissions that could be expected over 30 years?
[open response]%

Q5_B Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on efficiency, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.

If you were to allocate all of this money to efficiency what would be the maximum possible percent reduction in net carbon emissions that could be expected over 30 years?
[open response]%

Q5_C Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on decarbonization, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.

If you were to allocate all of this money to decarbonization what would be the maximum possible percent reduction in net carbon emissions that could be expected over 30 years?

[open response]%

Q5_D Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on carbon geoengineering, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.
If you were to allocate all of this money to what would be the maximum possible percent reduction in net carbon emissions that could be expected over 30 years?
With atmospheric carbon dioxide removal, it is theoretically possible to have reductions greater than net carbon emissions, in this case, the answer would be greater than 100%.
[open response]%

Q5_E Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on solar geoengineering, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.
If you were to allocate all of this money to solar geoengineering what would be the maximum percent change based on the following metrics that could be expected over 30 years?

Maximum possible percent reduction in temperature increase
[open response]%

Maximum possible percent reduction in ecosystem damage
[open response]%

Maximum possible percent reduction in human vulnerability caused by climate impacts
[open response]%

Q5_F Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on adaptation, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.
If they were to allocate it all of this money to adaptation what would be the maximum percent change based on the following metrics that could be expected over 30 years?

Maximum possible percent reduction in ecosystem damage
[open response]%

Maximum possible percent reduction in human vulnerability caused by climate

impacts
[open response]%

Q6_A You are given complete control over designing a global climate strategy. Including setting a CO_2 concentration target in 30 and 300 years. In your opinion, what should be the CO_2 concentration target in 30 years and 300 years?

Consider both the costs (such as the cost of cutting emissions) and benefits (broadly defined) but should ignore political factors that may prevent the world getting to an outcome that best balances costs and benefits for humanity.

The 2012 average annual CO_2 concentration is about 394 ppm and over the last decade it has been increasing at 2.1 ppm per year.

The CO_2 concentration target in 30 year:
[open response] ppm

The CO_2 concentration target in 300 year:
[open response] ppm

Q7_A Considering the political, economic and social realities of making current and future climate policies, please answer the following questions with your most likely prediction.

The 2012 average annual CO_2 concentration is about 394 ppm over the last decade it has been increasing at 2.1 ppm per year.

What do you think the most likely CO_2 concentration will be in 30 years?
[open response] ppm

Given the uncertainty in the above concentration, please indicate the range of possible CO_2 concentrations in 30 years, bounded by a low concentration estimate (the 10th percentile):
Consider the 10^{th} percentile estimate to be the estimate whereby the odds are 9 to 1 that actual concentration will be higher.
[open response] ppm

and a high concentration estimate (90^{th} percentile):
Consider the 90^{th} percentile estimate to be the estimate whereby the odds are 9 to 1 that the actual concentration will be lower.
[open response] ppm

Q7_B Considering the political, economic and social realities of making current and future climate policies, please answer the following questions with your most likely prediction.
The 2012 average annual CO_2 concentration is about 394 ppm over the last decade

it has been increasing at 2.1 ppm per year.

What do you think the most likely CO_2 concentration will be in 300 years?
[open response] ppm

Given the uncertainty in the above concentration, please indicate the range of possible CO_2 concentrations in 300 years, bounded by a low concentration estimate (the 10^{th} percentile):
Consider the 10^{th} percentile estimate to be the estimate whereby the odds are 9 to 1 that actual concentration will be higher.
[open response] ppm

and a high concentration estimate (90^{th} percentile):
Consider the 90^{th} percentile estimate to be the estimate whereby the odds are 9 to 1 that the actual concentration will be lower.
[open response] ppm

Q8 To what extent do you agree or disagree with the following statements:
[Strongly Disagree; Disagree; Disagree somewhat; Neutral; Agree; Somewhat Agree; Strongly Agree]

[Randomize order]

1. I worry that people expect technology will fix the changing climate.
2. Anthropogenic climate change is the most pressing issue facing humanity today.
3. Many problems in human society are wrongly attributed to climate change.
4. Unmanaged climate change will have catastrophic impacts on Nature.
5. Humans know enough about how nature works to be able to control it.
6. People have done a good job using technology to fix environmental problems.
7. Climate policies should be based on promoting human well-being over protecting the natural environment.
8. Unmanaged climate change poses very significant risks to values such as liberty, tolerance and diversity.
9. Every species on the planet has an equal right to live.
10. The natural world has value independent of any human preferences or human projections.
11. Unmanaged climate change will have catastrophic impacts on human society.
12. Technologies that work like nature are best.
13. We must develop new technologies to solve climate change.

Q9_A1 In your opinion, how serious of a threat do you believe climate change is to the following in 30 years time?
[No Threat, Minor Threat, Moderate Threat, Serious Threat]

1. Ecosystem services
2. Vulnerable people
3. Non-human nature
4. Future generations
5. Human infrastructure
   Human health

Q9_A2 In your opinion, how serious of a threat do you believe climate change is to the following in 300 years time?
[No Threat, Minor Threat, Moderate Threat, Serious Threat]

1. Ecosystem services
2. Vulnerable people
3. Non-human nature
4. Future generations
5. Human infrastructure
6. Human health

Q10 A few questions about your expertise in climate change research.

1. How many years have you been working on climate change related research?
   [0 years; 1-5 years; 6-10 years; 11-15 years; 16-20 years; 21+ years]

2. What percentage of your professional work in the past five years is dedicated to climate change related research?
   [0%; 1%-25%; 26%-50%; 51%-75%; 76%-100%]

3. Please estimate how many publications related to climate change you have authored or co-authored?
   [0 publications; 1-5 publications; 6-10 publications; 11-15 publications; 16-20 publications; 21+ publications]

6. How would you describe your expertise in the climate change field?
   [open response]

Q11 For each of the following actions, please indicate your level of expertise on a scale of 1-5 by choosing the appropriate number:
1 = low (e.g., no direct experience, anecdotal knowledge only)
3 = medium (e.g., some direct experience, but wide reaching)
5 = high (e.g., primary focus of my professional work)
[1; 2; 3; 4; 5]

1. *Conservation*
2. *Efficiency*
3. *Decarbonization*
4. *Carbon geoengineering*

5. *Solar geoengineering*
6. *Adaptation*
4. *Making trade-offs between the actions above*

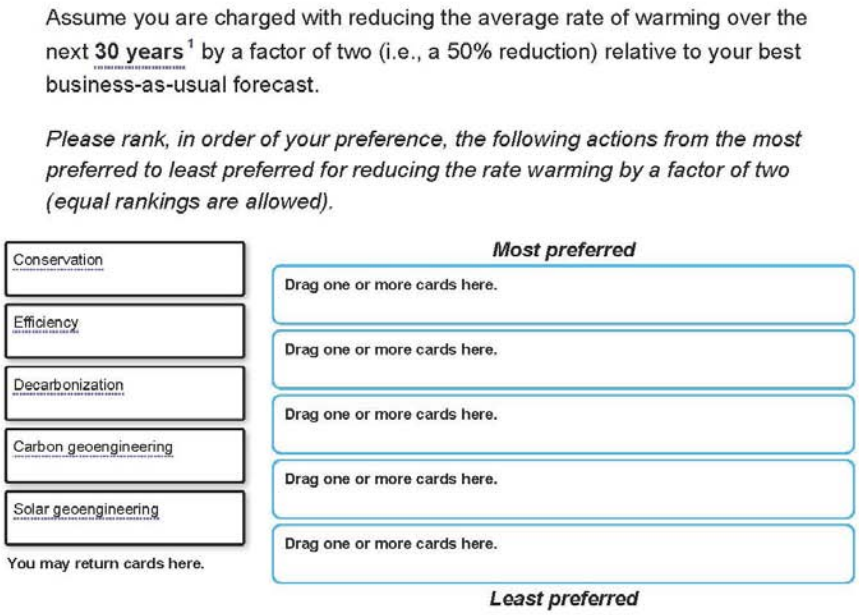
Q12 Please answer the following questions about yourself
What country do your currently live in?
[Open response]

How would you describe your political views?
[Very conservative (far right wing); Conservative (right wing); Moderate (middle of the road); Liberal (left wing); Very liberal (far left wing)]

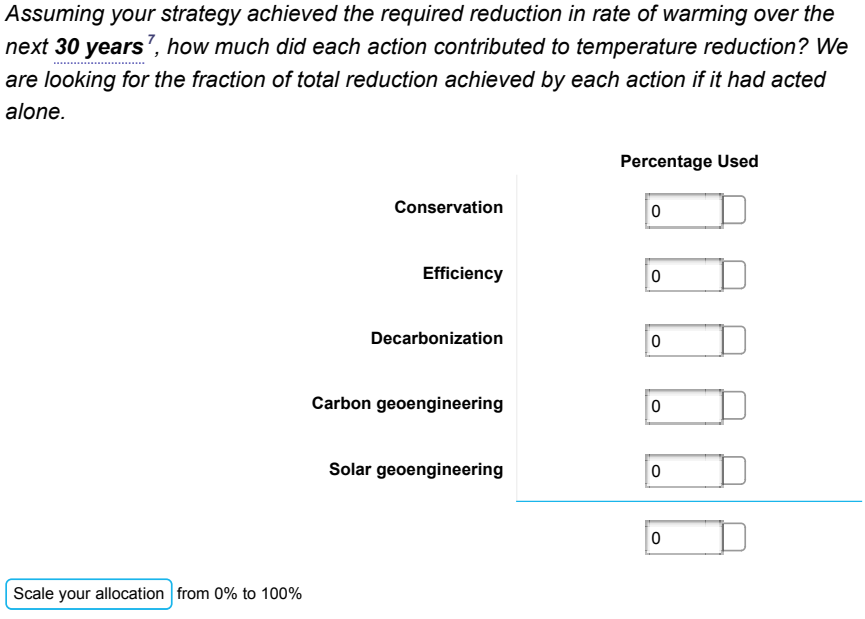
What is your gender?
7. *[Male; Female]*

Question examples

1) Card sort



2) Allocation allotment



3) Slider tool

The *Millennium Ecosystem Assessment* estimates that 20% of all species are believed to be threatened with extinction in the near future, and rates of biodiversity loss over various biomes are "substantial and predominantly negative."

Assume you are charged with lowering the ***rate of biodiversity loss*** *in* ***30 years***[1] *time. What fraction of total available resources for biodiversity loss would you commit to addressing climate change compared to other areas of potential interventions (e.g., land-use and habitat management, invasive species management, pollution control)?*

4) Multiple choice tool

To what extent do you agree or disagree with the following statements:

	Strongly Disagree	**Disagree**	**Disagree somewhat**	**Neutral**	**Agree Somewhat**	**Agree**	**Strongly Agree**
I worry that people expect technology will fix the changing climate.	○	○	○	○	○	○	○
Anthropogenic climate change is the most pressing issue facing humanity today.	○	○	○	○	○	○	○
Many problems in human society are wrongly attributed to climate change.	○	○	○	○	○	○	○
Unmanaged climate change will have catastrophic impacts on Nature.	○	○	○	○	○	○	○
Humans know enough about how nature works to be able to control it.	○	○	○	○	○	○	○

5) Open response

Suppose that 0.5% of the world's GDP (350 billion dollars per year) was spent on **decarbonization**, and suppose further that decisions about how to use the money to were made in the most efficient way possible. One might imagine that an apolitical board of experts was empowered to use the funds as effectively as possible to achieve the given objective.

*If you were to allocate all of this money to **DECARBONIZATION**[1] what would be the maximum possible percent reduction in net carbon emissions that could be expected over **30 years**[2]?*

[ ] %

APPENDIX C - PUBLIC CONCERNS ABOUT THE ETHICS OF SRM

Carr W., A. Mercer and C. Palmer (2012), Public concerns about the ethics of SRM in *Engineering the Climate: The Ethics of Solar Radiation Management*, edited by C Preston, Lexington Books, Maryland.

"Talk straight, make sure, don't screw up, and don't forget anything"

-Respondent 747

Introduction

In the past five years, a shower of reports published by think-tanks and scientific bodies have discussed future prospects for the geoengineering technologies currently being proposed in light of rising greenhouse gas (GHG) emissions. These reports have characteristically emphasized that social and ethical considerations should play a key role in geoengineering research, and insisted that public engagement is critical to the process of developing and debating geoengineering technologies. For example, the influential 2009 Royal Society report *Geoengineering the Climate* stated, "The greatest challenges to the successful deployment of geoengineering may be the social, ethical, legal and political issues associated with governance, rather than the scientific and technical issues" (2009: xi). One of the key recommendations of this report was to, "initiate a process of dialogue and engagement to explore public and civil society attitudes, concerns and uncertainties about climate change" (2009: xii). Likewise, a recent report on geoengineering produced by the Bipartisan Policy Center (BPC) emphasized that geoengineering raises, "new ethical, legal, and social issues of broad public concern" (BPC, 2011: 19) and that, "public engagement must inform the program agenda" (BPC, 2011: 17).

These types of explicit calls for public engagements and ethical inquiries on emerging technologies have grown in recent decades (Rogers-Hayden & Pidgeon, 2007). While both ethics and public engagement are increasingly considered critical and urgent aspects of the development of emergent technologies, they are rarely brought together in a meaningful fashion. Ethicists construct logical arguments, debate these arguments, and come to (often conflicting) ethical conclusions; while social scientists utilize engagement methods such as surveys, interviews, citizens juries, and focus groups to elicit public perceptions that may or may not be incorporated into decision making processes. But rarely are the arguments of philosophers and the concerns of the public brought into direct contact with one another. So far, work on geoengineering has followed a similar pattern. Despite being pursued concurrently, the small but growing body of academic ethics research on geoengineering (for example Gardiner, 2010; Hamilton, 2011a, 2011b; Jamieson, 1996, 2010; Preston, 2011) has remained largely separate from public engagements that probe knowledge about, and opinions of various forms of geoengineering (Leiserowitz, 2010; Mercer *et al.*, 2011; NERC, 2010; Spence *et al.*, 2010).

This disciplinary separation represents an opportunity lost. The potential synergies of philosophy and social science are notable – particularly in the context of emerging technologies. Social science research has indicated that public concerns about emergent technologies naturally gravitate towards social and ethical issues (Wilsdon & Willis, 2004; Wynne, 2007). Previous public engagements have revealed areas where average citizens question foundational assumptions being made by scientists and/or policymakers, and assert different visions of technologies and their future roles in society (Reynolds & Szerszynski, 2007; Walmsley, 2009). In other words, the basic concerns that individuals have about emerging technologies are inherently, if not always explicitly, linked to ethics. As such, social scientists are increasingly

attempting to create space in public engagement processes for the discussion of normative issues (Reardon, 2007).

If these types of processes were brought into contact with philosophical reflection, it seems plausible to expect mutual enrichment. It might be that particular ethical concerns that philosophers have not considered, or have not yet clearly articulated, arise in public consultation. Conversely, philosophers may have persuasive arguments that could reinforce or calm certain public concerns, or potentially raise problematic issues in public awareness. Philosophical work can help in interpreting and providing explanations of fundamental ethical concerns – such as concerns about justice or relations between human beings and nature – that may underpin what emerges from public responses. Collaborations of this nature could result in enriched understandings of social and ethical issues related to emergent technologies. In fact Borgmann (2006: 15) has described such connections as inherent and unavoidable,

> Social science without ethics is aimless; ethics without social science is hollow. In fact, the two fields inevitably overlap. There is no social science research that is not tethered, however indirectly, to concerns of social justice and human flourishing, and there are not ethical reflections that fail to appeal somehow to the actual human condition.

Purpose and Methods of this Paper

This chapter aims to initiate an interdisciplinary and mutually beneficial conversation between ethics and social science on geoengineering. Co-written by two social scientists and an ethicist, we bring together data from an international survey of public perceptions of geoengineering with current research on the ethical questions about geoengineering, either raised

by ethicists directly, or found in the ethics sections of major geoengineering reports. We look for areas where philosophical concerns dovetail with, develop, or reinforce public concerns; where they tend to diverge from such concerns; and where there are worries that seem important either to the public or to philosophers that do not arise in the other group. We suggest that dialogues of this kind could improve both public and philosophical engagement with geoengineering, and improve the research and development of SRM technologies.

Some stylistic challenges arose in merging our disciplinary backgrounds. Social scientists typically inhabit a world of quantitative and qualitative social data, and tend to prefer empirical statements to normative ones when describing study findings. But we found in constructing this paper that holding fast to disciplinary conventions can inhibit meaningful cross-disciplinary exchange. Presenting survey methods and results as is commonly done in social science may render findings of consequence to an ethics audience uninteresting or inaccessible. As such, our presentation of the data breaks with some social science conventions. We do not attempt to statistically quantify various positions, but focus instead on the significance of particular quotations for exposing shared and divergent concerns between the public and philosophers about the ethics of geoengineering.

The Survey

The data presented below comes from an international survey of public perceptions of one branch of geoengineering proposals referred to as solar radiation management (SRM). This survey focused on a particular SRM approach that would enhance atmospheric albedo by increasing the concentration of sulphuric acid droplets in the stratosphere (Royal Society, 2009). Scientists hypothesize that this technique could relatively quickly and cheaply lower global average temperatures by reflecting a small percentage of incoming sunlight back into space. This

type of intervention presents some significant ecological, social, political, and economic risks and uncertainties at varying scales from the local to the global. Both because of its potential benefits and risks, stratospheric aerosol injection has received significant political and scientific attention in recent years, and was the focus of this social science investigation.

The survey was conducted in Canada, the United States, and the United Kingdom in November and December of 2010. The survey questionnaire was designed to assess respondent familiarity with geoengineering more broadly, with SRM in particular, and respondent opinions about these topics. The large majority of survey questions were close-ended, meaning they presented respondents with limited answer choices that were statistically analyzed to make generalized statements about the broader population (See Mercer *et al.*, 2011 for a quantitative analysis of this data). Three survey questions, however, were open-ended, allowing respondents the opportunity to describe their views in their own words. One such question asked respondents, "If you had the chance to talk to Solar Radiation Management researchers and decision makers, what would you say or ask?" While preceded by a short, unbiased description of SRM, to help provide standardized information to all participants, this open-ended question provided a place for respondents to discuss anything they felt relevant to SRM research or policy. The responses to this question highlight the significance of ethical concerns that members of the public have about SRM and provide insights into the nature of those concerns. Based on our analysis, just over 69% of the 2,809 survey respondents who chose to answer this question discussed issues that we identified as pertaining to ethical aspects of SRM. This indicates that the ethics of SRM are extremely salient to members of the public, even when encountering this topic for the first time.

Below we present the ethical concerns of the public using their own words.[16] We have included a large number of quotations to provide readers with an indication of how similar ethical concerns were expressed in different ways. We bring these public concerns together with those expressed in the professional ethics literature, drawing on published material from a number of academic sources. We have classified the quotations related to ethical aspects of SRM into seven broad themes, 1) negative side effects; 2) playing God and messing with nature; 3) the wrong solution; 4) distribution of harms and benefits; 5) the role of science, trust, and public participation; 6) governance of SRM technology; and 7) climate denial. These themes often overlap and respondents frequently refer to more than one theme in a single quotation. However, there is sufficient distinctiveness between each concern for it to be useful to separate them out.

We hope this approach of coupling social science data with professional ethics literature will allow an ethics audience to see the salience of ethical concerns to the public, to compare the ways in which average citizens describe those concerns to the ways professional ethicists treat similar issues, to see where there are different or competing concerns, and to begin envisioning how future interdisciplinary research, particularly on geoengineering, could benefit from further integration of public engagements and professional ethics reflections.

Ethical Concerns about SRM

1. Negative Side Effects

Many survey respondents raised major concerns about the potential unintended, negative side effects of SRM. Some respondents raised fairly sophisticated technical questions,

[16] We have corrected minor spelling and grammatical errors and shortened some quotations. .

> While I understand that volcanoes release sulphur particulates [...] is the particulate release intended to be on a similar magnitude, or much larger? Will these particulates be prone to causing an increase in lung cancer/respiratory disorders? Is it possible to increase the earth's albedo to a point where we could cool the earth from the surface, rather than atmospherically?

However, technical questions were rare in comparison to general concerns about the potential impacts of SRM on humans, plants, animals, and ecosystems,

> Would these solar emissions that you shoot into the sky have any impact on the health of humans, animals or plant life and will it affect the air we breathe?

> We were told that smoking was not harmful to our health. We were told that asbestos was not harmful to our health […] What kind of health problems might be expected or are we just changing one problem for another perhaps more costly?

These types of comments were more focused on the effects than the effectiveness of SRM proposals. Respondents expressing interest in potential side effects were less interested in the technical feasibility of SRM and much more concerned with the possible negative impacts. Many respondents were particularly concerned about side effects that experts might fail to predict,

> The thing that really worries me is the unforeseen effects. However much research you do, you cannot allow for all possible outcomes and once it's done it can't be undone. You cannot know for certain what the effect will be, however much research is done.
>
> You will never be able to fully determine the effects of Solar Radiation Management on nature. Even if there are no short term effects, there will be long term effects that may cause more damage than initial estimates.
>
> Manipulations of nature by humans have a history of turning out very badly, with unexpected side effects – such as introducing alien species of plants or animals into other areas – and even the effects that we have already had on the climate. Did anyone expect what has happened to happen? And we don't know for certain what changes to climate have been effected by humans and what changes are natural. Doing something on a global scale could be extremely risky […] There could be wild extremes of changes that were not predicted.

These responses embody a widespread sentiment among survey respondents that SRM has the potential to bring about unforeseen, negative consequences. These concerns are about more than *risks*, or the quantification of the chances of foreseen consequences coming to fruition. These concerns are about uncertainty and ignorance, or about not knowing the relevant parameters of natural systems or how they interact (Shackley *et al.*, 1998; Wynne, 2006). This sentiment was nicely captured in the following response,

> Testing Solar Radiation Management on a small scale over several years or seventy years for that matter would never allow you to predict what the effects would be on a global scale, our planet is unpredictable, we should never assume we know exactly how it works […] taking risks on our planet based on small scale research is frightening to me and I am sure many others also.

In worrying about unforeseen negative impacts of SRM on humans, the public shares the concerns of ethicists, and indeed geoengineering researchers as well. Admittedly, some of the specific risks raised by the public do not appear in the ethics literature. For instance, it does not discuss direct human health impacts from the use of sulphate aerosols (presumably because ethicists writing on this subject are familiar with scientific literature on the amounts and atmospheric location of the sulphates that would be involved, which makes such problems unlikely). But interestingly, several of the public responses explicitly refer to the possible impact of SRM on non-human nature – on the interests of individual living beings and on the health of ecosystems. Such harmful human impacts on organisms and ecosystems have featured in environmental ethics (for instance Rolston, 1989; Singer, 2009; Taylor, 1986) and have to some extent played a role in broader worries about climate change (Nolt, 2011; Palmer, 2011). But there is very little about these kinds of impacts in the geoengineering literature, though environmental ethicists would be expected to have concerns about this issue. More work to explore the ethical questions raised by SRM in terms of its direct impacts on non-human organisms and systems seems called for.

Respondents were not only concerned about the *risks* of particular side-effects, but also about associated *uncertainty* (where the probability of particular outcomes is not known) and

ignorance (where some of the possible outcomes remain unknown). What is more, the comments above suggest that some respondents do not believe that further research will result in all possible effects becoming known. Such sentiments mesh interestingly with Sarewitz's (2004) claim that additional research can actually open up new areas of uncertainty, rather than reducing it. This worry about uncertainty and "unknown unknowns" has been a major concern in all the relevant literature. The IPCC (2007: 15) notes, "Geo-engineering options . . . remain largely speculative and unproven, and with the risk of unknown side effects." Unsurprisingly, this concern has also featured in the ethical literature. As long ago as 1996, Jamieson (p. 327) argued that, "The problem with our technological interventions is that we often don't know the price of the meal in advance or even the currency in which it will be extracted." In the ethics literature more broadly, some form of precautionary approach is often defended in cases where outcomes are uncertain (e.g. Gardiner, 2006a). Precaution is not explicitly mentioned in these public responses, but may be a way to conceptualize how such concerns could gain traction in a policy context. It is worth noting, though, that not acting for precautionary reasons can itself generate alternative risks (Sunstein, 2005), since there are uncertain, potentially negative outcomes from *not* using SRM in the absence of greenhouse gas mitigation.

In the case of ethical concerns about side-effects, philosophers and the public have relatively similar responses to SRM. The communication of better information about the known risks of SRM to the public (for instance that threats to stratospheric ozone are much more likely than threats to human respiratory health) would bring these concerns closer. But worries about uncertainty and "unknown unknowns" are common to both groups. This overlap suggests one key area where social scientists and ethicists could work together to encourage more transparency about risk, uncertainty, and ignorance associated with SRM technologies,

encouraging more open and democratic discussions about both science and policy.

2. Playing God and Messing with Nature

A second ethical concern raised by respondents related to "messing with Nature" or "playing God." This overlaps with concerns about side-effects, since some respondents feared that "messing with Nature" could negatively rebound on human beings. But there was also a distinct concern about the ways in which human beings understand themselves and about appropriate human relations with the rest of nature,

> What gives you the right to mess about with nature and cause a potentially worse disaster than you're trying to prevent?

> I would say, Stop playing God, there is no easy way out. We must be logical and not go on making more problems for ourselves –You are making us all feel like goldfish in a blender. Thanks for nothing!

The central concerns here seem to be whether humans have a "right" to "mess about" with the natural world, and whether it is appropriate for us to shape the earth's climatic systems in accord with human intention. Here again, public concerns resembled those of ethicists, though ethicists have raised several different issues in this context. One kind of worry is about "the end of nature," as articulated by McKibben (2006) in the context of anthropogenic climate change. It is possible to argue that intentional geoengineering takes further steps towards "ending nature" because nature would no longer be "independently-directed." Keith (in Goodell 2010: 45) relatedly describes geoengineering as potentially bringing about "the end of wildness;" while

Hamilton (2011a: 21) sees SRM as, "a conscious attempt to overcome resistance of the natural world to human domination, the last great stride towards total ascendancy." Something like these arguments appears to be lurking in the public responses outlined above.

A second, related issue that also appears in these responses concerns human self-regard and the idea that intentionally controlling the earth's climate is an example of human hubris, arrogance, or self-aggrandizement. Hill (2007: 684) calls attitudes like this a "failure to appreciate one's place in nature" and a lack of "proper humility." As Hamilton (2011b:. 14, quoting Coady) puts it, one could see SRM as, "an unjustified confidence in knowledge, power, and virtue beyond what can reasonably be allowed to human beings." Although the respondents above might maintain that the problem with such overconfident attitudes is that they are *mistaken* – we *do not* in fact have the control over the climate we imagine – the attitudinal worry could remain even if humans *were* in (effective) control of the climate. That we *can* do something does not mean that a good or virtuous society *would* do it; as the second respondent above suggests, this might be taking "an easy way out" rather than addressing a more fundamental problem. Indeed, this may reflect another attitudinal issue – of human laziness and, perhaps, of superficiality. Some environmental ethicists (e.g. Sandler 2009) have developed accounts of environmental virtues, and Gardiner has specifically, though briefly, discussed these in the context of SRM (Gardiner 2010, 303). The idea that geoengineering is a kind of human over-reaching that reflects negatively on us (or, rather, on *some* of us) arises so widely in public responses, that further philosophical work on "playing God" and human virtue (including the idea of collective virtues) seems called for.

Preston (2011) has recently raised the question whether, in certain circumstances, deployment of SRM could be morally permissible despite these concerns, suggesting that such

worries should not necessarily be taken as *decisive*. After all, the attitudes displayed by allowing increasing greenhouse gas emissions are *also* morally troubling, and there could at some time in the future be a threat of runaway climate change, such that the risks of SRM appear to be much the lesser evil (Preston 2011, 471). Such arguments – though not made by any respondents here – are important, and indicate a potential need for further public discussion to explore ethical arguments about how, when, and whether justifications for the use of SRM may ever override deep ethical misgivings about intentionally manipulating the global climate. This may be a case where an important philosophical argument such as Preston's could form the foundation of future public engagement processes.

3. The Wrong Solution, Better Alternatives, and Technological Fixes

A third concern was that SRM is the *wrong solution* to the problem of climate change – a "technological fix" rather than something that gets to the heart of the problem. As such, a number of respondents asked whether alternatives to SRM might exist,

> Would there be any other alternative to Solar Radiation Management or other technologies similar that would solve global warming?

> What are the other options? Do we have better solutions?

> Are there any other alternatives currently being studied?

Some participants even suggested alternatives that they felt might be worth pursuing in place of SRM,

> Your time would be better spent trying to develop technologies that can remove substantial amounts of the emissions humans have emitted.

While this individual refers to technologies that *are* currently being researched and developed, namely carbon dioxide removal technologies, the overall message is that some members of the public were skeptical that all options for addressing climate change were being explored. In fact, the most frequent alternative raised by respondents was reducing carbon emissions,

> Why put large amounts of effort into reducing the amount of sunlight (which I think is a bad idea). Put efforts into developing non-carbon based (this includes not using plant/food for fuels) sources of energy such as nuclear, solar (which would seem to be hurt by reducing sunlight), wind and hydro. Also why not put efforts into making our use of energy more efficient to reduce the amount used.

> Understanding we are in serious trouble with global warming, I support efforts to stall or retard advancement. However, rather than a band-aid we need to STOP at all costs the emissions.

> I think it's better to tackle a problem at the source (i.e. cutting down on emissions) instead of combating/counteracting the effects with more man-made interference.

These comments indicate that rather than proposing alternative technological solutions to SRM (such as other forms of geoengineering), many respondents insisted that the problem should be tackled by cutting emissions. Some respondents specifically regarded SRM as a "quick fix" or "technological fix",

> Whilst using this technology will we carry on researching in other ways on how to stop climate change for good? Or will we just look to solar radiation management as a quick fix solution?

> This seems like another quick fix to an environmental issue we have. We need to stop trying to solve problems with ways that could cause more problems. Remember DDT????

Several interesting ethical ideas arise here. One is the thought that SRM is an "easy option" allowing us to carry on living in the same ways, while doing nothing about "fixing climate change for good." These comments call to mind Gardiner's (2006b, 2010; see also Hamilton, 2011b) discussions about the way climate change opens up possibilities for extensive moral corruption. A second idea is whether, as one respondent suggested, SRM is one of a series of cases where new technologies have been invented to "fix" a problem, but have ended up "causing more problems" themselves.

This may point the way to further useful philosophical work. Although a broader philosophical literature already exists on the idea of technological fixes, this has not been applied in any detail to geoengineering. Scott (2011, 208), in the context of agricultural technology,

notes that despite the term "technological fix" being widely used as a derisive label, people, "typically demonstrate an overriding preference for technological fixes." Indeed, a small number of survey responses displayed this exact preference,

> Why haven't you started yet?

> Please, please, please do geoengineering […] we must have the technology to adjust our atmosphere to protect ourselves from any eventuality.

These types of responses raise questions about whether something being a technological fix *matters* ethically, particularly if the outcomes of using it are better than the alternatives. This, in turn, generates further questions about the ways geoengineering might be regarded from the perspective of different ethical theories – those where *outcomes* are what matter, rather than those that focus on *principles* or *character*. More broadly, the idea of SRM as a technological fix provides an opportunity to explore contrasting attitudes towards technological innovation, both within and between different societies (Borgmann, 2006; Scott, 2011; see also Corner & Pidgeon, 2010).

While most respondents prioritized cutting GHG emissions, they disagreed about whether SRM should be pursued while working on emissions reductions, or whether research on SRM should be abandoned altogether. Most geoengineering studies agree that SRM is no "solution", but here we see the same divide. Scientists such as Crutzen (2006) propose research on geoengineering while also adamantly advocating for carbon mitigation; others, such as Kiehl (2006) reject the pursuit of geoengineering technology altogether, arguing that such high-risk

alternatives should not be on the table at this point. Similar division also exists in the ethical literature. Gardiner (2010) comes close to rejecting SRM research, arguing that our attention should instead be focused on GHG mitigation. However, Preston (2011), as we have seen, argues that we might be best to regard SRM as a last resort in the case of runaway climate change. Given that this distinction seems to be found in public responses, the scientific literature, and the ethical literature, there may be opportunities here for climate experts and ethicists to engage the public in discussions about the basic permissibility of SRM and other forms of geoengineering; about risk-risk tradeoffs between climate change and SRM, how such risks can be weighed and compared, and whether such trade-offs and comparisons are ethically permissible.

4. Distribution of Harms and Benefits

A number of respondents raised questions about the impacts of SRM on particular regions of the earth. Some were concerned about the impacts on themselves and on regions in which they have interests,

> What would be the expected changes in the weather – changes in the air, land, and water temperature – changes in the amount of sunlight, rain, snow, fog, occurring in the direct area of Canada in which I own a home?

But others raised questions about impacts on vulnerable or poorer regions of the world,

> What area of the world are you concerned with? Asia in particular has been hit with severe flooding but there seems to be more concern with coastal cities such as NYC so I question what part of the world will benefit.

How severely will this technology change weather patterns in the poorer parts of the world?

These questions about regional impacts suggest that the public are concerned about possible distributional justice issues related to SRM. Modeling studies do indicate that sulfate particle injection could alter regional precipitation patterns, particularly in Africa and Asia (Ricke *et al.*, 2010; Robock *et al*., 2008). This raises important regional justice issues, not least because those areas that have contributed least to creating the problem of climate change might be impacted most by this way of "fixing" it. These kinds of distributional justice concerns have been highly significant in the current ethical debate about climate change more generally, but have not been much developed in work on geoengineering ethics (Jamieson, 1996; Gardiner, 2010; Royal Society, 2009). Yet this is clearly salient for members of the public. And the issues here are particularly important, as the distributions of harms resulting from SRM would be much more clearly *intentional* than harms resulting from climate change, raising different questions about moral responsibility and legal liability (Hamilton, 2011b).

Respondents were not only concerned about the distributional effects of SRM on present generations but on future generations as well,

Will this kill my grand and great-grandchildren?

> My children and grandchildren are the future of this planet. We owe it to future generations to further explore ALL avenues of science AND restraint. We need to be much more aware and prudent, in our consumption and use of our natural resources.

These comments, anchored in the personal concerns people have for their children and grandchildren, indicated that respondents were also worried about the effects of SRM on the future. While ethicists have focused on the long-range effects of climate change itself, not much yet exists concerning the potential impacts of SRM on future people. Although Gardiner (2010) discusses SRM and the future in some detail, his concern is primarily with the moral corruption current generations display by putting future generations in the position where they may have to act "evilly" by using SRM to protect themselves from dangerous climate change.

In expressing concerns about distributional and intergenerational justice, as well as about the constraints on moral choices we might be leaving future people, the public has picked up on important justice considerations related to SRM. These concerns point to a pressing need for further studies of wide-ranging justice issues in the SRM context.

5. The Role of Science, Trust, and Public Participation

Respondents were also concerned about how scientific research into SRM would be carried out, and who would be in control of it. A number of questions were raised about the funding and conduct of research into SRM (including about the survey itself),

> What will be the benchmarks for success/failure, who will identify these criteria and how will these trials be funded?

> Who is paying for this research and who will benefit financially from the technology that emerges from it?
>
> Who pays you? How free are you to have an honest opinion? What environmental groups do you support? Are you asking because you value my opinion or because you need to spin the information to persuade me? What is a small scale research project and what effects will it have? Where will you do the research? Who is most at risk from this proposal? [. . .] how open are you to dialogue with independent media and environmental groups and the uninformed, non-academics like me? Will you call for round table discussions and offer all your data for perusal and invite all stakeholders to partake, including random people from every socio-economic sphere?

This last quotation also indicates a concern expressed by a number of respondents about the willingness of scientists to open their research up to public scrutiny and broader public dialog,

> Would the findings of the scientists be published in full for the public to study?
> Not to hide any information to the public like many wealthy corporations do in this country.
>
> I would like to know how long this research has been ongoing to reach this stage. Are we being told of all potential damage and dangers involved [. . .] Something should be done and I am in agreement with research but we should all be informed honestly throughout

each stage. Who would benefit financially from this? Would companies vie for business? How would it be funded???????????

Along with calls for openness, honesty, and transparency, some respondents openly questioned why they should trust scientists on this issue at all,

Why should the public trust you?

Why do you think the public should trust your judgment?

How could you trust even yourselves to not use the science for personal gain and which government in the entire world would not use it for political gain?

These comments reveal widespread suspicion about scientific research into SRM that operates at various levels, suspicion about motivation, suspicion about benefits, and suspicion about secrecy. Some of the comments suggest that these suspicions would be at least partially allayed if open and transparent scientific processes made research available to the public.

These types of concerns have certainly been anticipated in the major reports on geoengineering. The Royal Society (2009), Asilomar Conference (2010), British House of Commons (2010), BPC (2011) and Solar Radiation Management Governance Initiative (SRMGI 2011) have all suggested principles that should govern research into SRM, and ways in which public participation should be incorporated into the research process. The recent SRMGI report, published after this survey was carried out, explicitly raised issues about the funding of research,

and public perceptions of trust and liability. However, this is certainly a case where talk may be cheap. The announcement in the UK of a field trial of technology that could be used to deliver sulfate aerosols to the stratosphere in the future generated an international outcry in late 2011. Much of the outcry concerned the lack of public consultation about the research that led to the announcement (Macnaghten & Owen, 2011). This incident, which resulted in deferral of the field trial while further public consultation was carried out, indicates the importance both of keeping the public informed about scientific developments, and perhaps even providing the public with the opportunity to help frame research questions and goals (Stirling, 2005; Wilsdon & Willis, 2004).

6. Governance of SRM Technology

Alongside concerns about researching SRM, respondents expressed concerns about governance. Questions were raised about who would be in control of SRM technologies and who would be responsible if or when unexpected or negative outcomes occurred,

> What industries would develop the technologies and who would be responsible for implementing them? What kind of national and international oversight would there be and with what authority?

> Who would decide which part of the world would have their rain volume changed because of Solar Radiation Management and would that mean that some countries would need to become uninhabitable?

> How will you predict where effects such as extra rainfall will occur? And if the extra rain exacerbates flooding somewhere, how will it be dealt which? Who will take responsibility?

These types of public concerns were widespread, and raise questions about international relations and international responsibility. What governance regimes would deal with problems? And what would be an ethical way of doing so? Implicit here, as with the pursuit of scientific research, are questions about democratic participation in creating governance structures; in particular, how can those in hard-to-reach, but likely to be affected, locations be consulted? "With what authority" would there be national and international oversight?

Potential governance structures for SRM have been discussed in multiple publications, and by multiple parties, including the UN Convention on Biological Diversity (2010) and SRMGI (2011). However, these attempts to construct mechanisms for governing SRM do not carefully deal with all of the ethical issues that lie behind the worries expressed above. In particular, SRM generates different questions of moral responsibility than climate change, because of its intentional nature. If the implementation of SRM harms some nations, while benefiting others, new international justice questions are raised. SRM will be carried out from a point source or sources; it will be a decision deliberately made by some group or groups; it cannot be attributed to people now dead, and so on. Ethicists should explore the implications of these international justice questions raised by the governance of SRM very closely.

The importance of public engagement is at least as pressing in developing the governance of SRM technology as research into the technology itself. There has already been some discussion of the ethical requirements here: Jamieson (1996) considers the need for democratic

processes in the context of intentional climate change; Corner and Pidgeon (2010) describe upstream engagement as a potential mechanism for soliciting meaningful public participation in decision-making processes about SRM research and governance; and SRMGI (2011) discusses in some detail different forms of public participation in creating governance structures. But there is still work to do, and scrutiny is needed to ensure that espoused ethical principles of participation in decision-making are actually implemented in practice.

7. Climate Denial

Finally, and in line with research on public perceptions of climate change, a handful of respondents questioned the underlying assumption behind SRM research, namely that anthropogenic climate change exists at all,

> You are starting from a premise that is unproven, many would even say unfounded. That is, that human activity results in global warming (climate change). This idea is nothing more than a political maneuver to gain votes. Hard, peer-reviewed science indicates that the earth goes through cycles of warming and cooling. Nothing to be alarmed at.

> Why do you continue to waste money on charlatan theories and political grandstanding when overwhelming evidence suggests that the current climate changes are cyclical in nature and that carbon emissions have not been shown to impact climate nearly as much as the public has been led to believe?

It is important to acknowledge climate change deniers in this context for two reasons. First, as Jamieson (1996) notes, the prospect of geoengineering may create strange bedfellows. Those

who oppose SRM (and perhaps other forms of geoengineering) as unethical may find themselves in an alliance with those who oppose SRM because they do not accept climate change at all. Alliances over particular moral questions for widely divergent underpinning reasons are not uncommon, with alliances between feminists and conservatives against pornography being an obvious example (West, 1987). But in this case, an alliance between climate change deniers and those opposed to SRM for other reasons may well be a fragile one. If SRM could be implemented without requiring any significant change to "business as usual," in contrast to what is demanded by significant mitigation, politically and economically conservative climate deniers might easily shift to being SRM supporters. It is also clear that, right now, those who sincerely reject the science of climate change present another form of ethical opposition to SRM that has not been considered. This is an area where ethicists could inform future public engagement efforts aimed at exploring the relationship between climate denial and perceptions of geoengineering.

Conclusion

In this chapter, we have reproduced and discussed some of the key ethical concerns raised by the public about SRM, and brought these concerns into dialog with ethical debates found in formal reports and academic papers. This dialog has led us to draw a number of conclusions.

First, and most generally, we have shown that ethical considerations are central to public concerns about SRM. This has emerged in other public engagements (NERC, 2010; Parkhill & Pidgeon, 2011) but it is a point worth emphasizing. The core questions raised by geoengineering technologies in the public arena are, as the Royal Society (2009) anticipated, social, ethical, and political, rather than primarily scientific and technological. Over two-thirds of the responses to a

very broad, open-ended question on an international survey focused on what we have classified as ethics issues. This indicates that ethical questions are at the forefront of people's minds when they think about geoengineering, and it is these questions that the public will want to see addressed by scientists and decision makers (Wynne, 2006). If SRM is to gain *public* acceptance, it will need to gain *ethical* acceptance. And at the moment, there are many public ethical concerns that would need to be allayed – if, indeed, they can be. This, of course, assumes that for SRM to be deployed it *should* be widely ethically acceptable. Some might contest this, but all the major reports produced so far (for instance BPC, 2011; Royal Society, 2009; SRMGI, 2011) emphasize that geoengineering technologies should be developed ethically.

Second, we have shown that, in many cases, the concerns raised by the public are closely related to those articulated in ethics literature. Unsurprisingly, public concerns about the ethics of SRM are often expressed more informally than scholarly ones, and they emerge from personal life experiences and contexts, but they are recognizably the same concerns. Since the academic ethics literature on geoengineering is relatively small, public concerns flag important areas for future work. For instance, a number of public comments raised questions about the distribution of the effects of SRM, who would benefit and who would be worse off, and what questions about distributional justice this raises. There has, so far, been little ethical work on these questions. Even if it is unclear at present what the effects of SRM might be, further research on the ethical significance of the intentional nature of SRM in contrast with anthropogenic climate change seems particularly important.

However, the traffic here is not all one way. While raising issues that ethicists should explore, public concerns should also be subjected to critical scrutiny. In cases where popular claims or worries are based on factual inaccuracies, reflect inconsistencies, or are otherwise

problematic, ethicists should try to make alternative arguments available in the public sphere, perhaps by contributing to popular publications, public discussions, or participation in public engagements. Indeed, even where the majority of ethicists and the public appear to agree, there is still space for debate and objection. For instance, some members of the public viewed SRM as problematic because it intentionally interferes with natural processes. While this view is also held by the majority of environmental ethicists, it is, nonetheless, an argument that can be challenged on a number of grounds; for instance that "nature" has already been intentionally "interfered" with or that the whole human/nature distinction should be abandoned (Jamieson, 1996; Preston, 2011). Such arguments are not decisive; but bringing them into the public sphere could stimulate debate. Indeed, the salience of ethical concerns may indicate that the public would be interested in engaging in thoughtful and reflective treatment of these issues. Professional ethicists, then, should think about how to utilize intuitive ethical concerns raised by the public to facilitate and inform more complex and pertinent discussions about ethics and geoengineering in ways that are accessible and digestible.

There are, in addition, some arguments prevalent in the ethical literature about SRM that did not directly arise in comments from the public – for instance, the debate about whether geoengineering research itself creates a "moral hazard," causing people to be more reckless in terms of carbon emissions (Hale, 2010). Such arguments, in more popular form, deserve wider public debate and discussion.

Our third and final conclusion concerns the considerable space the responses discussed above reveal for mutual learning at the intersection of social science and ethical reflection on geoengineering. Social scientists can help ethicists to continue assessing the concerns of publics, including public conceptions of ethical issues, and how such issues can be effectively discussed.

Social scientists can also help to incorporate public engagements into ethical assessments of SRM technologies. Just as the public may raise new research questions via social science for ethicists, ethicists can inform future social science research in several ways, including, considering what ethical questions particular geoengineering proposals raise (for instance, about distributional and intergenerational justice, and about human relations to nature) and in assisting social scientists in facilitating public engagements that specifically target these questions. We conclude, then, that ethicists and social scientists can and should seek out ways to work together more closely on the social and ethical challenges posed by geoengineering for the benefit of public debate, scientific research, and policymaking.

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