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Public understanding of solar radiation management

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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 3105 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 associated with optimism about scientific research, a valuing of SRM's benefits and a stronger belief that SRM is natural, while opposition is associated with an attitude that nature should not be manipulated in this way. The potential risks of SRM are important drivers of public perception with the most salient being damage 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.

Keywords: geoengineering, solar radiation management, climate change, public opinion, public awareness

S Online supplementary data available from stacks.iop.org/ERL/6/044006/mmedia

1. 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 (Shepherd *et al* 2009). Known as geoengineering or climate engineering, this third response comprises an 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 sulfate 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 (Barrett 2008, Blackstock *et al* 2009, Shepherd *et al* 2009, NAS 1992) 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 (Shepherd *et al* 2009, Blackstock *et al* 2009, Keith *et al* 2010, Robock *et al* 2009, Corner and Pidgeon 2009). 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 decarbonize 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 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 dialog, 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 included 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 lack of studies directly assessing understanding and awareness of geoengineering, the increase in internet and printed media coverage (figure 1) suggests that the public is increasingly exposed to 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.

Deployment of SRM may well reshape humankind's view of nature. Given the profound implications of this technology,

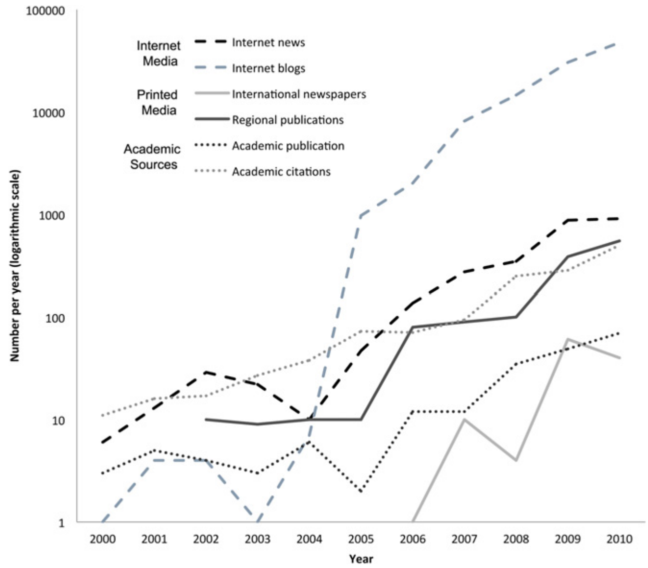


Figure 1. Growth in the number of publications about geoengineering from three media sources: internet (dashed lines), printed (solid lines) and academic (dotted line), from 2000 to 2010. Counts of internet news and blogs sites were established through date specific searches of geoengineering on Google 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.

leading researchers have called for public dialog (Blackstock and Long 2010, Keith *et al* 2010, Corner and Pidgeon 2009, Shepherd *et al* 2009, House of Commons 2010). As meaningful dialog is only possible if the participants have some coherent understanding of the technology, this study aims to inform the 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.

2. Methods

An extensively pretested Internet-based survey was completed by 3105 participants in Canada, the United Kingdom and the United States between 19 November and 7 December 2010. The subjects completed an 18-question survey instrument, which was divided into five sections (see the supporting material for the full text of the survey and screen-shots of the survey delivery, available at stacks.iop.org/ERL/6/044006/mmedia):

(1) Baseline knowledge assessment—Five Likert-scale and open-ended questions (questions 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 technological optimism—two multi-item Likert-scale questions were used to establish subjects' beliefs regarding global warming 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.

2.1. 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 wide socio and economic backgrounds. 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 3105. 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 influenced by these sources then the participant's responses were removed from the study. The resulting sample size is 2893.

2.2. Assessing bias introduced by the information section

It is unavoidable that providing the technical information about SRM biased the responses to some degree. The survey was designed and extensively pretested 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 (questions 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.

2.3. 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 cataloged and aggregated using statistical methods to establish baseline observations that can be tracked over time (Fischhoff and Fischhoff 2001). There are, however, two important limitations of using surveys on topics for which public opinion is not well formed. First, the rigid question 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 response 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 and/or small group exercises.

3. Results

3.1. 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 questions 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 in winter 2010. While these assessments are slightly different, the increase over time may suggest a trend of growing familiarity within the broader public consistent with the trends shown in figure 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 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 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'.

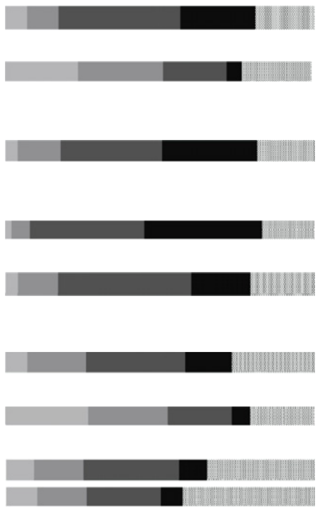
3.2. Opinions on geoengineering

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; 14% of the sample oppose this research, while 72% somewhat or strongly support it (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).

Table 2. Opinion elicitation based on a four-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	



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 toward implementation.

A number of additional questions were asked in order to better understand initial opinions about SRM (summarized in table 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 per cent 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%).

3.3. 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.

3.3.1. 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 is 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). Comparisons presented in table 3 suggest detractors hold significantly different opinions on these questions.

3.3.2. Opinions on global warming. Opinions on global warming also differ significantly between supporter and detractor groups, as shown in table 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 3. Mean comparisons of general opinions of SRM between supporter and detractor opinion groups. (Note: based on a four-point Likert scale: 1 = strongly disagree; 2 = disagree; 3 = agree; 4 = strongly agree.)

	Supporter		Detractor		
Exact question wording	Mean	SD	Mean	SD	t-statistic
Q15A: SRM will help the planet more than it will hurt it	3.00	0.65	1.75	0.87	25.2[a]
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[a]
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[a]
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[a]
Q15G: Humans should not be manipulating nature in this way	2.62	0.86	3.68	0.63	25.3[a]
Q15H: SRM is natural	2.43	0.83	1.59	0.80	17.8[a]
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[a]

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

Table 4. Mean comparisons of opinions on global warming between supporter and detractor opinion groups. (Note: based on a 5-point Likert scale: 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree.)

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

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

3.3.3. Opinions on risk and benefits. In the educational section of the survey, participants were presented with four benefits and five risks of SRM. Table 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.

3.3.4. 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% versus 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.

3.3.5. 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

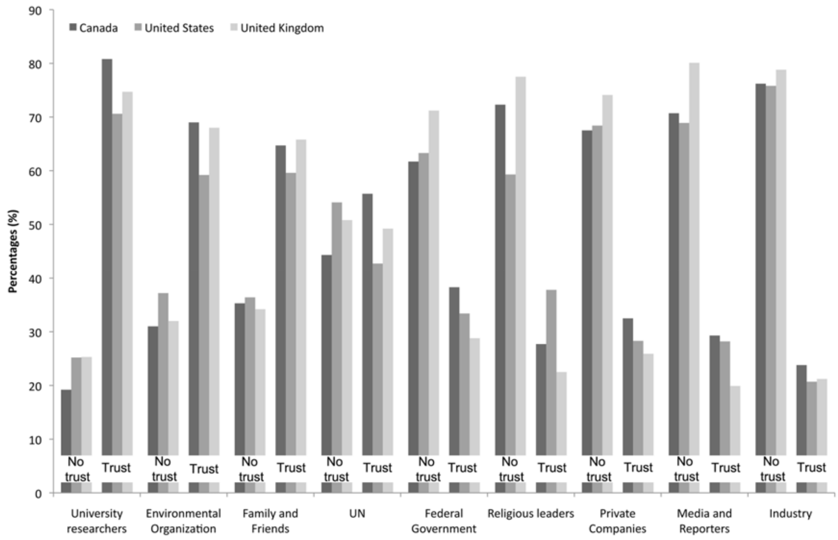


Figure 2. Subjects' trust in different groups, by country. 'No trust' denotes the percentage of respondents that somewhat or completely distrust a particular group, while 'trust' denotes the percentage of respondents that somewhat or completely trust that group.

Table 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. (Note: based on a four-point Likert scale: 1 = not at all important; 2 = somewhat unimportant; 3 = somewhat important; 4 = very important.)

	Overall		Supporters		Detractors		
	Mean	SD	Mean	SD	Mean	SD	Unknown
Benefits							
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%

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.

3.3.6. 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 ($\lambda = 0.4$, $p < 0.001$). 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 in this way (Q15G). Notably, both opinions of global warming and demographic information, including political views and education level, are not important predictors in this analysis.

3.4. 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

Table 6. Discriminant loadings for the important predictor factors in the discriminant function to describe supporter and detractor opinion groups. (Note: the other predictors included in the function are: Q6A, Q6B, Q6D, Q7A, Q7B, mean of 14E-I, Q15F and political views. The cross validated classification shows that overall 86% of the cases were correctly classified.)

Important predictor factors	Discriminant loading
Q10: Do you think scientists should study Solar Radiation Management?	0.697
Q15G: Humans should not be manipulating nature in this way	−0.611
Importance of benefits (mean of Q14A-D)	0.596
Q15H: Solar Radiation Management is natural	0.497
Trust in organizations (mean of Q14A-I)	0.423
Q7C: We must develop new technologies to solve global warming	0.368
Q15C: Solar Radiation Management should be used so we can continue to use oil, coal and natural gas	0.332
Q15F: The earth's temperature is too complicated to fix with one technology	−0.314

chemicals in the atmosphere 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. 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 available media (figure 1) and increase in assessed familiarity from 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 to 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 environmental engineering, 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. 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. 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 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 either 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 dialog 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 and Cvetkovich 2000). As future policy and governance debates concerning SRM continue, scientists are likely in a unique and trusted position of influence. Also noteworthy is 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 questioned 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, do not screw up and do not 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's 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.

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