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Public concerns about solar geoengineering research in the United States

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Solar geoengineering is receiving increased private research funding at a time of growing social media speculation about government weather control. This can complicate public deliberation on solar geoengineering research. Using interviews ($N = 64$), focus groups ($N = 10$), and a national survey ($N = 3076$), we explore initial impressions of the US public on solar geoengineering research, including views on research and beliefs that atmospheric modification to combat global warming is currently ongoing. We find more opposition than support for research and a strong preference for research based in universities. Twenty percent of respondents believed it is partly or completely true that the US government is currently putting chemicals into the atmosphere to counteract global warming, and nearly half of respondents are unsure. We theorize belief in ongoing solar geoengineering not primarily as misinformation, but as para-environmentalism, representing a permutation of environmental concern that deserves further research and engagement.

Solar geoengineering, also known as solar radiation modification (SRM), involves blocking incoming sunlight to cool the planet globally through approaches such as marine cloud brightening or stratospheric aerosol injections. At present, this concept is studied through modeling. Scientists have worked to outline research agendas for SRM, such as the one proposed by the US National Academies of Sciences, Engineering, and Medicine in 2021. This study recommended $100–200 million over five years for research[1], but public funding on this scale did not emerge.

Yet in the past two years, philanthropic foundations have announced more than $100 million USD of support for research[2], and the UK government announced a $75 million USD research program[3], meaning that the field is now receiving research dollars aligned with the scale recommended in the National Academies report —albeit without consistent governance mechanisms or integrated focus areas. The recommendations from the National Academies included robust public engagement in guiding and shaping the research agenda, including from climate-vulnerable communities and underrepresented groups[1]. Public engagement is valuable in research and research governance for many reasons: it can help scientists define research questions, ensure the activities are in line with social priorities, and support research legitimacy[4–8].

One challenge for meaningful public involvement in SRM research is low public familiarity with SRM. Previous social science research has consistently found that most people have never heard of geoengineering and know very little about it[9]. When people are introduced to the idea of SRM, qualitative research has found a common set of concerns that arise: concerns about unintended consequences, unequal impacts, and the need to address the root causes of global warming[10]; as well as reluctant and conditional acceptance of research given the risks of climate change[11,12]. Social scientific research has found that the public wants to be involved and consulted in SRM research and risk assessment—e.g., this was widely supported in a study that involved focus groups in 22 countries, but the study also found some skepticism over the value of public engagement, with questions about media trends towards polarization and sensationalism[10].

Indeed, public engagement is complicated by the post-truth media ecosystem, often theorized in terms of misinformation or disinformation. For example, when Hurricane Helene brought devastating flooding to western North Carolina in the autumn of 2024, the idea arose—as espoused by one member of Congress and critiqued by President Biden[13]—that "they" control the weather, referring to government control of hurricanes. This sentiment relates to an older conspiracy regarding chemtrails, or the idea that governments or elites are depositing chemicals in the atmosphere for harmful purposes such as mind or population control. Communication researchers have examined the chemtrails conspiracy on social media, studying Facebook content through the lens of misinformation[14], YouTube recommendations[15,16], Twitter posts[17–21], participatory conspiracy culture on Reddit[22], and the role of celebrity endorsement of chemtrails on social media[23]. A few studies draw from fields like anthropology or psychology and use qualitative and textual methods to study how people "awakened" into

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realizing about chemtrails[24], or interpret chemtrails as part of a cosmology where global elites are taking control[25], as well as how the structures of the Internet figure into collective sense-making[26].

Two previous surveys can illustrate how widespread these beliefs are. In a survey in the United States, Canada, and the UK, fielded in 2010, 2.6% of participants believed that it is completely true that the government has a secret program that uses airplanes to put harmful chemicals into the air, and 14% indicated partly true[27]. Those beliefs increased over time: in a survey fielded in 2016, Tingley and Wagner found that 9% of Americans declared it as completely true and a further 19–29% as somewhat true, with no apparent difference by party affiliation or strength of partisanship; they also examined social media discourse, finding that conspiratorial views had accounted for ~60% of geoengineering discourse on social media by then[21]. However, the media ecology has evolved since 2017, making it useful to update this picture—especially since the storyline around chemtrails has changed. For example, a 2023 study of tweets by Müeller-Hansen et al. found that 32% of tweets about stratospheric aerosol injection were conspiracy-related, but they also found that there was a trend toward lower shares of conspiracy-related tweets around 2016, raising questions about whether content moderation by platforms could be impacting public perceptions[20]. There may also be shifts in how these subjects are conceptualized and the language people use to represent them.

For meaningful public engagement with solar geoengineering, it is important to understand not just how prevalent these ideas are, but what might be driving them. In this analysis, part of a broader mixed-methods study on mapping the social landscape for net zero and climate technologies, we conducted local expert interviews ($N = 64$ included SRM, out of 113 total) and focus groups with members of the public ($N = 10$, two per region) in five regions within the United States: Alaska's railbelt region, the Northern Sierra in California, coastal Maine, north-central Oklahoma, and northern West Virginia. The focus group protocol invited participants to consider the most pressing issues for their region, their thoughts on the goal of net zero, their thoughts on the benefits and risks of carbon dioxide removal, and then finally solar geoengineering, meaning that responses to questions about SRM were in the context of climate change and energy system transformation. This qualitative work informed the design of the survey from a national sample ($N = 3076$), with oversampling of the five regions mentioned above. The focus groups and interviews also allowed us to learn more about the associations people have with this belief that solar geoengineering or weather modification is already ongoing, aiding in interpreting the survey data. Based on the qualitative work, we interpret the beliefs in ongoing atmospheric modification to combat global warming as a permutation of environmental concern, which we call para-environmentalism, and describe in the discussion section.

With respect to solar geoengineering, the study sought to understand the following set of research questions: (1) What are people's initial associations with SRM? (2) Do people support research? If so, whom do they want to conduct the research? What do they think about how it should be done? (3) How prevalent are ideas that chemtrails or geoengineering is currently happening, and what informs them? Who is likely to hold those beliefs?

Results

Familiarity with SRM

Consistent with previous research[9,28], most survey respondents reported low levels of familiarity with SRM (57.5% said it was new to them; 24.1% said they were just a little familiar; 14.7% said they were somewhat familiar, and only 3.6% said they were very familiar with SRM). In a hierarchical linear regression model (Table 1), controlling for demographics in the first block, we evaluated how familiarity with SRM was associated with political ideology, religiosity, and general interest in science and political news. In terms of demographics, younger ($\beta = -0.19$, $p < 0.001$), male ($\beta = -0.10$, $p < 0.001$), minorities ($\beta = -0.05$, $p = 0.035$), and more educated participants ($\beta = 0.04$, $p = 0.037$) reported more familiarity with SRM. Additionally, conservatives ($\beta = 0.09$, $p < 0.001$), those more interested in political news ($\beta = 0.11$, $p < 001$), people for whom religion was more important ($\beta = 0.11$, $p < 0.001$), as well as those who were interested in science ($\beta = 0.18$, $p < 0.001$), also reported more familiarity with SRM.

Perceptions of SRM and SRM research

In both interviews and focus groups, participants were asked what their initial thoughts, questions, or concerns about SRM were. Initial reactions to SRM were coded and grouped into a few basic categories (see Box 1 for indicative quotes from interviewees). The majority of interviewees expressed concerns about unintended consequences and had an initial reaction of skepticism, often paired with observations that questioned the track record of human intervention into complex systems. This group overlaps with a group who can be characterized as strongly rejecting solar geoengineering. Yet it also overlaps with a group that conditionally supports research due to the severity of climate change, even though they are unhappy about the prospect. No interviewees were enthusiastic supporters of research, and the open-ended survey responses also indicated that this position was extremely rare. A smaller number of respondents had an initial reaction that solar geoengineering was impractical, due to perceptions of it being expensive or ineffective, and so they deemed it not worth studying. Finally, there was a group that was simply unsure about the prospect and felt like they needed to know more to opine, and also a group who believed that geoengineering was already ongoing.

Table 1 | Predictors of self-reported familiarity with SRM and support for SRM research (standardized regression coefficients are shown, listwise deletion)

	Familiarity with SRM	Support for SRM research	
Block 1:			
Age	**−0.19*****	**−0.17*****	**−0.17*****
Female	**−0.10*****	−0.01	−0.02
White	**−0.05***	−0.01	−0.01
Hispanic	−0.03	0.02	0.02
Education	**0.04***	**0.04***	**0.05***
Income	−0.01***	0.00	0.01
R^2	0.06	0.07	0.07
Block 2:			
Political ideology	**0.09*****	**−0.22*****	**−0.25*****
Interest in political news	**0.11*****	**−0.04***	0.03
Importance of religion	**0.11*****	0.01	−0.01
Environmental identity	0.04	0.12***	0.13***
Science identity	**0.18*****	0.03	0.04
$\triangle R^2$	0.07	0.11	0.11
Block 3[a]			
Chemtrails are true	**0.09*****	**−0.18*****	--
Atmospheric modification is already happening	**0.11*****	--	**−0.11*****
ΔR^2	0.07	0.03	0.01
Adjusted R^2	0.13	0.21	0.19
F-test	$\boldsymbol{F_{11, 2549} = 35.15}$***	$\boldsymbol{F_{12, 2542} = 57.98}$***	$\boldsymbol{F_{12, 2544} = 52.35}$***

Assumptions related to hierarchical linear regression, like normality and multicollinearity, were met/corrected. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

The bold values indicate significant predictors in the regression model.

[a]These two variables were highly correlated ($r = 0.66$, $p < 0.001$). They were analyzed separately to avoid multicollinearity issues.

Table 2 | Prevalence of initial reactions to SRM in open-ended survey responses

Reaction type	Prevalence	Examples
1. Skeptical and cautious	22.4% (n = 690)	Risky, dangerous, scary, "more harm than good", unintended consequences
2. Skeptical and cautious, but pointing to the need for research	4.3% (n = 132)	"There is a potential benefit, but it could also harm. We need to do more research to insure the benefit outweighs the negative impact", "further testing is needed", "It's a very interesting idea, but a lot more thought and research would have to go into it before implementation. It sounds very risky".
3. Strong rejection	25% (n = 770)	Strong language about outcomes like "devastation", "disaster", "It will kill Earth"; statements about playing God ("It's a very bad idea. Nobody should be messing with God's Earth. PERIOD."); stupid, crazy, insane; statements in the imperative mode ("Stop messing around with nature. All of your supposed knowledge will bring destruction!")
4. Impossible, expensive, or impractical	4.3% (n = 131)	Impossible, expensive, costly, unfeasible, will not work, waste of money, unrealistic
5. Association with solar panels	3.6% (n = 110)	Solar panels, getting energy from solar, electricity from solar (while SRM is not connected with solar energy, the word "solar" has these connotations for some)
6. Chemtrails	1.3% (n = 41)	Chemtrails, spraying the atmosphere with planes, people trying to control our weather, "solar geoengineering has been going on for over 20 years LOOK UP"
7. Strong support for research	.03% (n = 10)	"I feel solar geoengineering is a great idea. It's a way that we could possibly help save our planet," "I think it is a good idea and I really support it".
8. Science fiction	2.4% (n = 74)	Science fiction, "Star Trek stuff", bad disaster movies in general — in order of frequently mentioned: episode of *The Simpsons* where Mr. Burns blocks out the sun (n = 13), *The Matrix*, *Snowpiercer, Futurama, "*The plot of Highlander II. Nobody wants the plot of Highlander II".

Box 1 | Initial reactions on solar geoengineering

1. Skeptical and cautious: This group's dominant reaction was skepticism. "To be honest, it sounds like something we could screw up really bad. It's kinda like medicine, the healthcare industry today, when you get sick, they want to give you some pill, that then has some side effects. And then they want to give you a pill for the side effect, and then that will have the side effect. And so it's almost like a marketing genius, where they get this domino effect of them fixing the ailments that they caused. And pretty soon, you're eating pills like Skittles, and they're making money hand over fist. But you've got yourself in a revolving door of unintended consequences. And if I think that it will screw up the planet, let's quit doing what we're doing, rather than try to screw with it some other way. I mean, that's my kitchen table, a common-sense approach. Now, maybe it needs to be studied more. I don't know enough about it, to call myself an authority on it. I certainly don't know enough about it to have an opinion that I would ardently defend. I want to be able to learn and to change my mind. But I'm telling you that what my gut is, and my initial prejudice is, that if we screwed it up by messing with it, don't screw it up more by messing with it more" (AK-1).
2. Skeptical and cautious, but pointing to the need for research: This group had a similar cautious, rational, and emotional stance as the first, but also made clear statements about how research was warranted. "I can't believe I'm going to say this. I wouldn't have said this 20 or 30 years ago, but I will say it now. I don't think we have a choice anymore. I think it's really unfortunate that we're in a position where we can't make progress quickly enough to avoid the worst impacts of climate change … we have to start experimenting with these technologies to find out whether or not they have any of the irrational negative side effects that people fear so that we know when the time comes which ones we can deploy safely and effectively…. So better to start experimenting with this and figure out what's going to work now than responding 50 years from now from a position of crisis" (CA-18).
3. Strong rejection: Some respondents rejected SRM outright. This could be because of concerns about risk, or because it is perceived as a false solution. "I look at this, and my first reaction is this is a lot of work to avoid doing what we need to do. I mean, we know what we need to do … and if we start removing the urgency to do it with some of these interventions, it literally clouds the issue. Right?" (ME-13).
4. Impractical: Another group doesn't see SRM as pragmatic, cost-effective, or workable from a social standpoint, so doesn't pay the proposals much heed. This isn't so much a "false solution" discourse as a "it won't work as a solution" discourse, and was often expressed from interviewees who had right-leaning positions on other issues such as the cost of climate mitigation.
5. Unsure: These respondents were unsure and preferred not to opine until they learned more.
6. Already happening: This was not a large group among our local expert interviewee sample, but the view was expressed in three of ten focus groups. It was also expressed by local experts when talking about the feasibility of SRM and the implications of research. In eight local expert interviews, people brought up the concern that other people would perceive SRM as part of a conspiracy. These ranged from offhand comments, e.g., "I can only imagine that the late-night AM radio talk shows that used to talk about chemtrails will have a whole new topic to talk about with this, and good luck with that" (WV-8) to more serious predictions of political dissent, e.g., "I think the implementation would freak out the populace to a really major extent. I think 20% of us would be willing to go to war over it" (CA-4).

To understand what initial associations the public has and assess the representativeness of these views, we examined responses to an open-ended item in the survey. Respondents were given a brief description of solar geoengineering (see SI), and asked, "What is the first thing that comes to mind when you think about solar geoengineering?" Responses were coded according to the categories above (see Table 2). Many respondents responded by repeating back elements of the definition (e.g., "reflecting sunlight" or "solar geoengineering"), or expressed uncertainty ("not sure," "I don't know"); those responses, along with missing data, were not coded (n = 965, or 31.4% of all respondents). Responses indicate that while many people have not formed initial reactions to SRM, those who have tend to express concern or rejection.

Table 3 | "Do you support or oppose further scientific research into solar geoengineering?"

	Total	Democrat	Republican	Independent	Other party ID/ not sure
Strongly support	11.8% (362)	19.9% (197)	6.2% (54)	8.8% (79)	9.6% (32)
Somewhat support	20.9% (642)	30% (297)	12.9% (112)	19.6% (174)	18% (59)
Neither support nor oppose	23.5% (721)	23.6% (234)	19.4% (168)	23.8% (212)	32.6% (107)
Somewhat oppose	16.4% (504)	14.9% (148)	17.9% (155)	18% (160)	12.5% (41)
Strongly oppose	27.3%(845)	11.5% (112)	43.6% (378)	29.7% (161)	27.1% (89)

Parenthetical data indicates the absolute number of responses.

Table 4 | Beliefs in airborne chemical programs

Question	Is it true or false that the United States government has a secret program that uses airplanes to put harmful chemicals into the air (often called "chemtrails")?	Is it true or false that the United States government is currently operating a program that uses airplanes to put chemicals into the air in order to counteract global warming?
Completely false	33.6% (1030)	21.8% (669)
Somewhat false	7.3% (224)	8% (245)
Unsure	38.9% (1195)	49.6% (1524)
Somewhat true	10.3% (317)	12.5% (383)
Completely true	9.9% (303)	8.1% (250)

Table 5 | Predictors of belief in airborne chemical programs (standardized regression coefficients are shown, listwise deletion)

	Chemtrails are true	Atmospheric modification is already happening
Block 1:		
Age	**−0.05****	**−0.10*****
Female	**0.22*****	**0.09*****
White	−0.02	−0.02
Hispanic	0.01	0.01
Education	**−0.10*****	**−0.06****
Income	**−0.09*****	**−0.08*****
R^2	0.06	0.04
Block 2:		
Political ideology	**0.26*****	**0.23*****
Interest in political news	**−0.09*****	−0.04
Importance of religion	**0.13*****	**0.12*****
Environmental identity	−0.03	−0.01
Science identity	−0.03	−0.01
$\triangle R^2$	0.13	0.09
Adjusted R^2	0.19	0.13
F-test	$\boldsymbol{F_{11,\ 2544} = 54.52}^{***}$	$\boldsymbol{F_{11,\ 2546} = 34.18}^{***}$

Response categories for both outcome variables were coded as completely false = 1, somewhat false = 2, unsure = 3, somewhat true = 4, and completely true = 5. Assumptions related to hierarchical linear regression, like normality and multicollinearity, were met/corrected.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Solar geoengineering research preferences

When asked specifically about support for scientific research in the survey, there was more opposition than support (Table 3). Further, Table 1 shows results from a hierarchical linear regression analysis predicting support for research, with demographics in the first block, ideology and other individual attributes in the second block, and beliefs about chemtrails and atmospheric modification in the third block. There were no gender or racial differences in support for research, but older participants were less likely to support research. People with higher education were more likely to support research, as were those who identified more strongly as someone concerned about protecting the environment (measures of environmental identity and science identity are based upon van der Werff et al. 2014)[29]. Conservatives were less likely to support research, as well as people reporting greater interest in political news, people who indicated they believed chemtrails to be true, and those who indicated they believed airborne interventions were already happening.

Those respondents who did not oppose further research ($n = 1729$) were also asked, "Who do you think should do research on solar geoengineering?" (multiple responses were allowed). Researchers in universities (71.3%) were preferred, followed by governments (43%), nongovernmental organizations (43.8%), private companies (32.6%), and citizens (16.7%).

The idea that geoengineering is already happening

In three out of ten focus groups (WV-1, OK1, and CA-1), there were participants who introduced the idea of "chemtrails", as well as the idea that geoengineering is already happening. This was also confused with weather modification (e.g., the idea that flooding in Dubai had been caused by cloud seeding). Two survey questions aimed to probe the prevalence of these ideas: first, we asked a variation of a question used by Tingley and Wagner (2017) and Mercer et al. (2011) about chemtrails. Then, we asked a question about whether the government is operating a program that uses airplanes to put chemicals into the air to counteract global warming (Table 4).

Based on a hierarchical regression, being younger, female, conservative, religious, and having less education, and family income were significantly associated with both these beliefs (Table 5).

When comparing surveyed people who expressed an opinion (i.e., either true or false) about whether chemtrails ($n = 1881$) and atmospheric modification programs (AMP) were already happening ($n = 1552$) ("Don't Know," $n = 1193$ for chemtrails; $n = 1522$ for AMP) using a two-tailed t-test, those who expressed an opinion were more likely to report higher levels of environmental identity (chemtrails: $t = 5.35$, $p < 0.001$; AMP: $t = 5.03$, $p < 0.001$) and higher levels of science identity (chemtrails: $t = 9.94$, $p < 0.001$; AMP: $t = 9.17$, $p < 0.001$), be more liberal (chemtrails: $t = 8.16$, $p < 0.001$; AMP: $t = 5.64$, $p < 0.001$), be more interested in political news (chemtrails: $t = 9.25$, $p < 0.001$; AMP: $t = 8.89$, $p < 0.001$), have higher education (chemtrails: $t = 5.59$, $p < 0.001$; AMP: $t = 4.14$, $p < 0.001$) and have higher family income (chemtrails: $t = 5.11$, $p < 0.001$; AMP: $t = 3.89$,

$p < 0.001$). They were also more likely to indicate that they were familiar with SRM (chemtrails: $t = 6.51$, $p < 0.001$; AMP: $t = 9.35$, $p < 0.001$); however, those who expressed an opinion related to chemtrails indicated greater support for SRM research ($t = 2.03$, $p = 0.042$) but expressing an opinion related to AMP had no significant relationship with support for SRM research ($t = 1.37$, $p = 0.17$). We also examined whether there was an association in the survey data between belief in chemtrails or ongoing atmospheric intervention with environmental identity or interest in science, but those beliefs were not significantly related (Table 5).

Discussion

Our findings provide important implications for public engagement and communication around SRM, research program design, and the politics of SRM.

More respondents oppose SRM research than support it, contrary to previous studies

Support for research was nuanced and conditional in the qualitative research, and highly divided in the survey. This indicates that increased investments in publicly visible research could face social backlash in the current social context. Here, only 32.6% of participants supported research, and 43.7% opposed it, with 27.3% of respondents expressing strong opposition (and with 23.5% not supporting nor opposing). Compare this with Mahajan et al. (2019) (81% of participants supportive, just 7% strong opposition), or Mercer et al. (2011), with 72% of participants supportive, and 14% opposing[27,30]. Rosenthal's (2023) results were more comparable to this survey, finding that 50.3% of US respondents supported research and 16% of respondents opposed it, with 7.9% having strong opposition[31].

We would caution against an interpretation that support has simply gone down over time, though, given the continued low familiarity with the topic. While this was not a framing study, other framing studies have found that negative messages have influenced support for research programs more than positive ones[32,33]. It is possible that the introductory paragraph used in this study, which was based on Rosenthal (2023) and designed to be balanced in mentioning risks (see Methods), nevertheless influenced reported support for research due to the number and types of risks described. Framing effects are common for information disseminated about emerging issues with which the public has low familiarity. This divergence of findings from other studies indicates the need for more research on this phenomenon as the public learns more about it.

Initial reactions to solar geoengineering are well understood

While this study found less support for research, the open-ended survey responses and qualitative data provided remarkable consistency with the qualitative literature on how people initially respond when confronted with the idea of solar geoengineering—namely, a strong initial response dubbed by earlier researchers as the "primal scream" to convey the emotional content and disgust at the climate situation[11], highly reluctant and deeply conditional acceptance of further study[11,12], and concerns about accountability and controllability[34]. In one sense, the social science literature has answered the question of what people think about solar geoengineering, and these findings have been repeated in this study. More research that simply catalogs or tracks initial perceptions may not be particularly illuminating. A critical review of solar geoengineering perceptions literature by Dove et al. (2024) argues that solar geoengineering perceptions research that looks exclusively at support and approval is a missed opportunity for other lines of inquiry, such as cross-cultural perspectives on public engagement with SRM; how to build capacity in SRM deliberations, particularly in the Global South; and how vulnerable populations see justice in the SRM context[35]. We agree with their recommendation to pursue other lines of inquiry, given that the literature on initial reactions is relatively established and consistent. It is also important to note that perceptions are likely to change over time. Braun et al.[36] investigated how cooling-off periods after the reception of new information shape perception, finding that acceptance of SRM increases over time, with this acceptance increasing over longer cooling-off periods[36]; further research could focus on the factors that shape perception over time.

Beliefs in chemtrails or in ongoing government intervention in the atmosphere are not fringe ideas at this point in time, and can be understood as part of a broader para-environmental movement

Ideas about ongoing atmospheric modification are likely to be important to the politics of solar geoengineering and shape its research and governance. Even though people who hold these ideas are more likely to be conservative, people in both parties are unsure about it. While only 1.3% of people took the open-ended question as an opportunity to say something about chemtrails—indicating a relatively small percentage of people who are actively driving this idea —a much larger portion of the population is reportedly open to the idea that airborne modification is ongoing, with 20.6% of respondents stating that this is somewhat or completely true. The qualitative data indicate that we need to understand people who are concerned or unsure about ongoing solar geoengineering not as simply misinformed, right-wing, and anti-science; people from both parties expressed uncertainty. One explanation is that people are simply unsure.

For those who do believe that airborne modification is happening, we might better characterize these beliefs as para-environmental ideas (see Box 2). The defining features of para-environmental ideas are that they are not grounded in empirics (even when the producers and users of these ideas might be deeply interested in empirics), and they don't possess the legitimacy of environmental ideas; hence, they are trafficked outside environmental institutions[37] and by people who may not have "environmentalist" identities. Yet para-environmental ideas have roots in traditional environmentalist concerns about the unintended consequences of chemistry, industrial technology, and agriculture, especially when it comes to the under-regulation of big corporations. This means communication strategies that address those dimensions are needed. Practically speaking, this suggests that one-way consultations (such as federal agencies taking comments) will not be able to address broad public concerns, and a need for two-way, interactive engagement with experts who are prepared and able to empathetically answer questions about emerging technologies like 5G, weather modification, and broader environmental challenges.

What do we make of the large percentage of people who are unsure whether chemtrails exist, or whether interventions to combat global warming are already happening? One way of looking at this situation is an educational gap. This observation is in tension with how many scholars of public engagement and climate change communication think about the problem; these fields have moved on from the deficit model that treats publics as blank slates in need of information[38]. Practitioners in nongovernmental organizations working on public engagement have embraced variations of Arnstein's ladder of citizen participation[39], which views education or "informing" as a lower form of engagement. Yet people in our focus groups did express their needs in terms of "being educated on these topics", indicating a demand for not just better "information," but information put into some kind of ordered, shared context: it's not just about receiving bits of data, but having a structure and process to make meaning. This demand for education is not unsurprising: a study that involved focus groups on climate intervention in 22 countries found that information and education was the most discussed form of engagement, constituting a first step that could enable more intensive forms of engagement[7].

In conclusion, we can make a few general recommendations about how to approach engagement and communication given these findings.

On the one hand, the uncertainty about ongoing atmospheric modification can be seen as an opportunity that could mitigate eventual public adoption of inaccurate beliefs. The communications literature finds that initial, inaccurate or conspiratorial beliefs tend to persist[40]. Providing individuals with accurate information is unlikely to lead to belief change when those beliefs are entrenched or have been repeatedly reinforced by political actors, organizations, media content, and those in one's social circles[41]. Disseminating accurate information about solar geoengineering before conspiratorial beliefs are formed and reinforced can be important, as can

Box 2 | Para-environmental ideas surfaced in interviews and focus groups

Ongoing geoengineering that is leading to environmental consequences. "When we looked at water and snow samples this last winter, they came back so full of aluminum, barium… cobalt six, all these different things, lead, sulfur soot. This is actually coming from the jet fuel itself. That is the stuff that is creating this layer that is actually causing the bad UVs to come in…. I mean, what's happening in the Pacific Ocean right now, it's being dimmed and it's not doing well. The ocean is not doing well. Things are dying. And then that stuff is blowing over here to the West Coast, and we have a lot of air traffic. It's very concentrated. That is what's actually causing the supposed climate change, the trapping of the greenhouse gases or the trapping of the heat and the sun. This is actually not from what we thought it was. And that is a game-changer for me. Like you, I've been spending years studying climate change, and I'm like, oh my gosh, we're looking at it incorrectly…. I'm watching a fast die-off right now. I don't have the birds I used to have just two years ago. I don't have the bees. I don't have the biodiversity. The forest is quiet. We don't have the fish in our rivers. I mean, this is happening fast. It's a real problem." (Interviewee, CA-16).

Weather modification—here linked to the failures of recycling, as two topics where the public has little visibility and control.

"I think that the state [of West Virginia] is more distrusting of the government than it is uneducated… I think it's this distrusting thing that causes the hesitation for change. For instance, like the state of Tennessee. This is not a conspiracy; it's like a FOIA [Freedom of Information Act] request, read it yourself. They stopped all weather modification spraying over the state of Tennessee. We've got that, we've got droughts, and we've got all these problems, and we've all just seen what happened in Dubai. It's not a conspiracy, you know, they've got weather modification. And they're spraying chemicals in our air. And we hope that that's okay…. And I don't know that it's denying climate change, as it is asking, what about these other things that are major contributors? Like, we've been separating our trash for recycling for how many years now? They don't separate it. It all goes to the same landfill. You can feel crazy about it and say, 'that hasn't really happened', until you make a trip to the waste management. So they're not taking our plastics out. We're not utilizing them for something else. If we had solid programs, and we could see that we're making an impact in what we're doing… I have friends who tell me that, well, it makes me feel like I'm doing my part. Well, I want to do my part too, I want that plastic recycled, because what is it doing to our environment?" (Focus group participant, WV Group 1).

Solar panels emit radiation. "The solar panels are wonderful. But the radiation that they emit, and putting them in our house, is way more than what your microwave or your cell phone puts out….So there's a lot of things behind the science, that unless you do a deep dive and read the studies like they do at Morgantown… and most laymen do not read all of that boring, what they may think is boring, scientific information. When you sample radiation, what do they call that, the Geiger counter, is that what they call it? It's enough for cancer." (Focus group participant, WV Group 1, same respondent as above).

Changes to light rays. "As far as the environment, I believe in scientists and the facts, and somehow the government or press or something has to expose the real facts in a way that people believe it and understand it. I think that's the biggest failure because every news channel is different. And "60 min", places like that sometimes show really good studies on what's going on…. The other thing, I do work with a scientist who deals with, like you say, the generations, billions of years. And he claims that light is changing, that comes down to earth, it's changing. And he found that people who have migraines and stuff like that, it's all about the light going into your sinuses, into your brain. It doesn't come in as light. It comes in as energy. And they're working to change that by filtering certain rays out of it…." (Focus group participant, CA Group 1).

Destruction of the fungus sphere. *[Looking at NOAA diagram of stratospheric aerosol injection, see Methods]*. "That's supposed to be spores. We have been systematically destroying our fungus sphere…. There should be dead wood just lying in piles all over the place, but people see that as a fire hazard, and so they always haul off their branches and logs instead of growing mushrooms on it in their backyard or burying them. So we don't have enough fungus to create the particulates that would be both reflecting the sunlight and acting as, I'm not sure what the word is, like the rain droplets. Every rain droplet forms around a fungus spore, and so if you don't have enough fungus spores in the air, you don't get rain. And I think that's a big reason that we've been in a drought….. I mean, as RFK Junior was just saying in his last speech I heard, just focusing on the numbers of carbon, of atmospheric carbon, it just ends up creating negative incentives for people to spend a bunch of money so they can make a bunch of money building a bunch of stuff that doesn't necessarily solve the problem, or at least not in the best way to do it. Oh, build a machine where we can use a bunch of cobalt that was mined by African slaves and build something that is going to break and be thrown in a dump after 10 years so that we can pull a little carbon out of the atmosphere. Meanwhile, our farmland is turning into a desert and it's just not going to fix that" (Interviewee, OK-18).

techniques such as belief inoculation or prebunking interventions, whereby individuals may be warned and provided with strategies for refuting and resisting inaccurate information[40,42,43]. For example, inoculation or prebunking would involve (1) warning individuals that they may be exposed to various forms of misinformation about solar geoengineering circulated in media or by others with whom they interact and then (2) immediately providing them accurate information.

On the other hand, interventions that frame the problem solely as misinformation in need of correction are likely to provoke a feeling of being manipulated by the very population that is already concerned about elite manipulation of the environment. If we look through the lens of para-environmentalism, we can see that simply providing technical info to publics earlier into public debate is not going to address the concerns that people have about power inequalities and agency[10], the histories and present contexts of environmental degradation[44], and so on. Two-way engagement methods that offer the time to discuss these emotional dynamics[45] and broader issues are going to be important, and discussions without a path towards actions of some kind will also frustrate people. But the message is that providing specific, accessible information on solar geoengineering needs to be combined with other methods of civil society engagement, which open up space to deliberate more fundamental concerns about environmental decision-making, technology, and power. We can make two specific suggestions about this, given the findings of this study. One is that local and regional universities could be especially important in this educational effort, given that a majority of respondents are done by scientists at universities, but that trust in elites can be low. Funders may be overlooking these smaller universities that have real relationships in their communities. The second is that more research needs to be done to understand populations that may hold para-environmental views, and engagement can be designed with these people in mind. For example, this study found that younger people and females were more likely to believe in ongoing atmospheric modification. Is this because of patterns of social media use, spillovers from the anti-vaccination movement with its links to alternative wellness culture or "conspirituality"

and negative experiences with official healthcare institutions[46–49], or other factors? Further research will be needed to understand this, but researchers, governments, funders, and engagement practitioners can begin thinking about engagement strategies that can meet different people where they are.

A basic underlying point is that investment in both basic information and education is going to be a precondition for effective public involvement in research governance, and SRM governance more broadly. The results of this study indicate serious challenges for a meaningful, fact-based social deliberation on solar geoengineering research in the absence of a corresponding investment in public education and engagement.

Online methods

This mixed-methods study involved ten focus groups and 113 interviews, followed by a survey. Themes emerging from the qualitative research informed the survey design. The qualitative work was done over periods from 2021 to 2024 in five regions: northern West Virginia, coastal and central Maine, north-central Oklahoma, Alaska (primarily the railbelt region), and the northern Sierra in California. These regions were selected to include a diverse set of human, economic, political, and biophysical geographies with different potentials for new climate and energy technologies, and different challenges in the energy transition; we also took into account existing relationships to enable on-the-ground collaboration when selecting these particular areas, since local connections are important in qualitative research. For this paper on solar geoengineering, we did not perform an analysis of differences among regions.

The mixed-methods approach was used to identify themes whose prevalence we wanted to examine using the survey; however, the interview data is not directly comparable to the survey, given that the interviews were with local experts (e.g., professionals, including community members viewed as having expertise or authority on matters relating to energy and the environment), and the survey population is a general public that is likely less familiar with these topics.

Qualitative methods

Semi-structured interviews

We conducted interviews in-person and on zoom from 2022 to 2024. Interviewees were identified according to the following stakeholder categories of interest: state, federal, and local government, including energy, sustainability, and planning roles; energy sector experts in both fossil fuels and renewables; environmental NGOs and academic experts; agriculture and fisheries experts and practitioners; Indigenous government officials and organizations; community groups focused on local development, health, and wellbeing; environmental justice organizations; labor and workforce development (see Table 6). Efforts were made to balance gender, ethnicity, and age. Respondents were contacted by email to arrange interviews. Out of a total set of 113, 64 interviews discussed solar geoengineering, after questions about pressing issues in the community or region, local responses to climate change, thoughts on the energy transition, and thoughts on carbon dioxide removal approaches.

For the solar geoengineering portion, respondents were shown a diagram, produced by NOAA, entitled "Solar Climate Intervention Methods" and viewable at https://cpo.noaa.gov/atmospheric-aerosols-and-their-potential-roles-in-solar-climate-intervention-methods/. This diagram depicts incoming solar radiation which is reflected by (1) Surface albedo enhancement, (2) Increasing the reflectivity of marine clouds (MCB), (3) Increasing the amount of stratospheric aerosol (SAI), (4) Space-based methods, and (5) Decreasing the amount of high-altitude cirrus clouds (CCT). They were then asked about their initial thoughts or questions about the risks or benefits of solar geoengineering approaches.

Respondents were asked:

- In thinking about solar geoengineering, what are some of the initial questions, concerns, or opportunities that come to mind?
- What do you think the potential risks and benefits of solar geoengineering might be?
- Do you think there should be research in this area? If so, how do you think it should be done?

Interviews were transcribed by a professional service and coded by two independent coders in NVivo 14, using a coding guide that was developed and refined from the data.

Focus groups

We conducted ten focus groups from September 2023 to August 2024, in the following locations: Chico, CA; Portland, ME; Morgantown, WV; Wasilla, AK; and Oklahoma City, OK. Focus groups ranged from 6 to 12 participants. Respondents were recruited using a local marketing research firm according to a screener that recruited for local demographics, along with political affiliation, age, gender, and race. Respondents were paid an incentive of $125–$150 for a 90-min session.

The focus group protocol was more structured than the semi-structured interview protocol. After informed consent and first-name introductions, the first 30-min module discussed how respondents expect climate change and energy transition to affect people in their area. Respondents were given handouts that described the greenhouse gas emissions profile and energy system in their state, and a graph from the US Long Term Climate Strategy, as discussion prompts. The second 30-min module included a five-minute video produced by Vox on carbon removal, "The tricky plan to pull CO2 out of the air," from April 6, 2023, and two handouts describing different carbon removal concepts. The third 25-min module, focusing on solar geoengineering, began with a six-minute clip from CBS Saturday Morning, originally aired on April 22, 2023, titled "To mitigate impacts of climate change, some turn to controversial "geoengineering." This video clip was chosen because it offers differing viewpoints on SRM research and explains the key concepts at a level that is aimed towards the general public, and it represents solar geoengineering in a way that the public might organically come across the topic if they were flipping channels on a Saturday morning.

Respondents were asked:

- In thinking about solar geoengineering, what are some of the initial questions, concerns, or opportunities that come to mind?
- What do you think the potential risks and benefits of solar geoengineering might be?
- Do you think there should be research in this area? If so, how do you think it should be done?

Focus group transcripts were also coded by two independent coders in NVivo 14, using an inductively developed coding guide.

Survey data

The survey was fielded from Sept. 4 to Sept. 23, 2024. Participants ($n = 3076$) were recruited and compensated by YouGov. The sample included 2000 US General Population participants with oversampling from Alaska ($n = 189$), West Virginia ($n = 196$), Maine ($n = 189$), Oklahoma ($n = 205$), and Northeastern California ($n = 297$). Participants in the main General Population sample ($n = 2000$) were matched to a politically representative "modeled" sampling frame of US adults on gender, age, race, and education (see Table 7 for survey demographics).

Following informed consent, the survey proceeds as follows. This paper presents results from Block 4.

[Block 1: Desired economic basis]

Different places rely on different economic activities. For example, some places have economies based in natural resources, agriculture, or manufacturing. Other places have an economy driven by service industries like health care or tourism, or knowledge jobs in education, technology, and creative fields.

1. Thinking about your community, what would you say the most important economic activity has been in the past? What industries or

Table 6 | Interview respondents

WV-1	Nonprofit
WV-2	Nonprofit
WV-3	State govt
WV-4	State govt
WV-5	Labor / workforce
WV-6	Business / industry
WV-7	Regional govt
WV-8	Local govt
WV-9	Nonprofit
WV-10	Local govt
WV-11	Local govt
WV-12	Business / industry
WV-13	Agriculture
WV-14	Local govt
WV-17	Nonprofit
WV18-	Fed govt
WV-19	Nonprofit
CA-1	Nonprofit
CA-4	Nonprofit
CA-5	Nonprofit
CA-10	Nonprofit
CA-12	Nonprofit
CA-14	Media
CA-16	Nonprofit
CA-17	Academia
CA-18	Business / Industry
CA-20	Nonprofit
CA-23	Tribal govt
ME-1	Academia
ME-2	Nonprofit
ME-3	State govt
ME-5	Business / Industry
ME-6	Nonprofit
ME-7	Academia
ME-9	Business / Industry
ME-10	Labor / Workforce
ME-13	Academia
ME-14	Nonprofit
ME-15	Nonprofit
ME-18	Business / Industry
ME-19	Local govt
AK-1	Business / Industry
AK-3	Nonprofit
AK-5	Nonprofit
AK-8	Nonprofit
AK-10	Government
AK-11	Nonprofit
AK-12	Nonprofit
AK-14	Nonprofit
AK-15	Government
AK-20	Regional govt
AK-21	Business / Industry

Table 6 (continued) | Interview respondents

AK-22	Nonprofit
AK-23	Nonprofit
AK-24	Academia
AK-25	Nonprofit
AK-29	Government
OK-4	Nonprofit
OK-6	Business
OK-7	Nonprofit
OK-12	Nonprofit
OK-15	Government
OK-18	Agriculture
OK-20	Government

economic activities supported your community when it was being created? [open-ended]

2. Thinking about the future of your community, what do you think is the most desirable economic activity for your community going forward? [open-ended]
3. Please rate your agreement with the following:

[Seven-point scale: Strongly disagree, disagree, somewhat disagree, neither agree nor disagree, somewhat agree, agree, strongly agree. Randomize all items]

a. Industrial development can be compatible with a healthy environment.
b. Making tangible products through industrial activity is important for having a good regional economy.
c. Our country has developed to the point where we don't need industry or manufacturing to have a good economy.
d. There is too much industrial activity going on in my community.
e. I support more industrial development in my community.
f. I would describe my community as disadvantaged.
g. My community has sacrificed too much already for economic development.
h. New industrial developments help more people in my community than they hurt.

Now, we want to ask your thoughts on new types of industrial or manufacturing projects in your area. We are asking about projects that require new infrastructure for making new products or goods.

i. Members of my community receive a fair share of the benefits of new industrial and manufacturing projects.
j. If I wanted to, I could influence whether or not controversial projects would take place in my community.
k. The procedures that protect public health and the environment from potential risks of new projects in communities like mine have been developed in a fair way.
l. If a decision had to be made about setting up new projects in my community, I would be able to express my views to the developers in charge.
m. If a decision were made to start new projects that I did not support in my community, there are procedures in place to allow me to make an appeal.

[Block 2: Net zero familiarity and perceptions]

As you may know, the United States has a goal to have net zero emissions by 2050, meaning the country would release no more carbon dioxide or other greenhouse gases into the atmosphere than it removes. To achieve this goal, Americans will need to use significantly less energy from fossil fuel sources such as oil, coal and natural gas, and use significantly more energy from renewable sources such as wind and solar.

Table 7 | Survey sample demographics (*N* = 3076)

Variables	*M* (SD) or Percentage (*n*)
Age	51.33 (17.05)
Female	53.9% (1657)
Race	
White	71.1% (2186)
Black	9.5% (291)
Hispanic	8.2% (252)
Asian	3.3% (101)
Native American	1.7% (51)
Two or more races	4.1% (125)
Other	2.3% (70)
Education	
Less than a high school diploma	4.1% (125)
High school degree or equivalent	29.3% (902)
Some college	21.2% (653)
2-year college	10.3% (318)
4-year college	21.7% (666)
Post-graduate degree	13.4% (412)
Family income	
Less than $10,000	6.2% (191)
$10,000–$29,999	17.8% (549)
$30,000–$49,999	15.5% (477)
$50,000–$79,999	20.1% (617)
$80,000–$149,999	21.1% (648)
$150,000 or more	9.1% (280)
Prefer not to say	10.2% (314)
Party identity	
Democrat	32.2% (991)
Republican	28.2% (867)
Independent	28.9% (889)
Other	10.7% (329)

[Note: Item 8 should appear on a separate screen from the paragraph above. Respondents who do not "pass" this comprehension check (option a) should be screened out].

4. What was the main point of the paragraph you just read about net zero emissions? [present response options in random order].
   a. Americans will need to use less energy from oil, coal, and natural gas and more energy from sources like wind and solar.
   b. Americans will need to use more energy from oil, coal, and natural gas and more energy from sources like wind and solar.
   c. Americans will need to use more energy from oil, coal, and natural gas and less energy from sources like wind and solar.
   d. Americans will generally need to reduce use of energy from all sources (oil, coal, natural gas, wind, solar, etc).
5. When you think about achieving net zero goals, what comes to mind first? [open-ended]
6. How do you feel about the goal of net zero? Do you favor or oppose the United States taking these steps to become net zero by 2050?
   [Strongly oppose, somewhat oppose, somewhat favor, strongly favor, not sure]
7. Suppose the United States put in place serious efforts to reach net zero by 2050. Based on your current knowledge, how likely is it that you or your community would need to take the following actions?
   [Very likely (4), somewhat likely (3), not too likely (2), not at all likely (1), not sure (98), I/we already do this (99)].
   a. Switch from a gasoline-powered car to an electric vehicle, or other modes of getting around, like public transit, walking, or biking.
   b. Eat more plant-based foods, rather than red meat such as beef and pork.
   c. Renovate buildings to run on electricity rather than natural gas, for instance by replacing gas-powered furnaces with appliances called heat pumps.
   d. Construct a new facility somewhere in our region for mining or processing minerals such as lithium, copper, and nickel for making batteries used in electric vehicles and renewable energy systems.
8. If the United States greatly reduces energy production from fossil fuel sources such as oil, coal, and natural gas and increases energy production from renewable sources such as wind and solar, how likely do you think this transition… [randomize] [Very likely, somewhat likely, not too likely, not at all likely, not sure]
   a. Would lead to unexpected problems for your region?
   b. Would not happen fast enough to prevent severe problems from climate change?
   c. Would end up harming you more than benefitting you?
9. How much do you agree or disagree with the following statements? I believe that policies to achieve net zero…
   [Strongly disagree, disagree, somewhat disagree, neither agree nor disagree, somewhat agree, agree, strongly agree]
   a. will bring new economic opportunities to my region.
   b. are part of an elite plan to use climate change as a reason for the government to exert more control over the lives of everyday people.
   c. are part of a plot called the "Great Reset."
   d. will limit my freedom to choose how I live.

[Block 3: Carbon removal]

The United States is investing in efforts to stop emitting greenhouse gases that cause climate change. Getting to net zero involves changing transportation, industry, buildings, agriculture, and power plants so that **less carbon dioxide reaches the atmosphere**. This process is often called **mitigation**. Mitigation will require increasing the manufacturing of solar panels and batteries for electric vehicles, and mining and refining minerals to make them.

However, there are some activities, like flying or shipping, where we lack technologies to fully reduce emissions. In a net zero world, some remaining emissions that are hard to get rid of are balanced by **carbon removal**, which involves removing carbon from the atmosphere *after* it has been emitted. Planting new forests or farming in ways that store more carbon in the soil are also methods of carbon removal.

New technologies are being developed for carbon removal. One approach is **direct air capture and carbon storage**, where carbon dioxide is filtered from the air and compressed. Another approach is **biomass energy with carbon removal and storage**, where plant matter such as waste from logging or agriculture is burned to produce electricity. The emissions from this process are captured at the power plant. In both of these approaches, carbon dioxide needs to be transported and put into wells so it can be permanently stored deep underground.

10. Please indicate how much you agree or disagree with the following statements:

[Strongly disagree, disagree, somewhat disagree, neither agree nor disagree, somewhat agree, agree, strongly agree]

   a. I would support my community/region hosting a facility that manufactures batteries for electric vehicles.
   b. I would support my community/region hosting a biomass energy facility with carbon capture and storage.
   c. I would support my community/region hosting a direct air capture and carbon storage facility.
   d. I would support my community/region hosting a facility that manufactures solar panels.

e. I would support my community/region hosting a facility that refines minerals used to build a renewable energy system.
f. Overall, I think my community/region would benefit from efforts to build an industry in carbon removal.
g. Overall, I think my community/region would be harmed by efforts to build an industry in carbon removal.

[Block 4: Solar geoengineering]

11. Some people have heard about solar geoengineering before, and some people haven't. How familiar are you with solar geoengineering?
    [Very familiar, somewhat familiar, just a little familiar, It's new to me]
    Solar geoengineering means reducing the amount of sunlight that reaches the Earth. One type of solar geoengineering that scientists are exploring is called stratospheric aerosol injection.
    Scientists have observed that when volcanoes erupt, they release gases into the upper atmosphere that block sunlight from reaching the Earth's surface. This blocking of sunlight cools the planet.
    Based on that effect, scientists have proposed using high-altitude aircraft or balloons to release special gases into the atmosphere to help make the planet cooler. But there may be some problems with this solution. Some scientists think the release of the gases can harm the ozone layer. The gases may also harm the environment and agriculture. They may also affect regional climates, for example, by impacting the amount of rain that falls in certain places.
12. What is the first thing that comes to mind when you think about solar geoengineering? [open-ended]
13. Do you support or oppose further scientific research into solar geoengineering?
    [strongly support, somewhat support, neither support nor oppose, somewhat oppose, strongly oppose]
14. Who do you think should do research on solar geoengineering?
    [Governments, researchers in universities, nongovernmental organizations, private companies, citizens, I do not support further research] [Multiple responses allowed]
15. Is it true or false that the United States government has a secret program that uses airplanes to put harmful chemicals into the air (often called "chemtrails")?
    [Completely false, somewhat false, somewhat true, completely true, unsure]
16. Is it true or false that the United States government is currently operating a program that uses airplanes to put chemicals into the air in order to counteract global warming?
    [Completely false, somewhat false, somewhat true, completely true, unsure]
    Please indicate how much you agree or disagree with the following statements about yourself:
    [Seven-point scale: Strongly disagree, disagree, somewhat disagree, neither agree nor disagree, somewhat agree, agree, strongly agree. Randomize all items]
17. I think of myself as someone who is concerned about the environment.
18. Being environmentally friendly is an important part of who I am.
19. I think of myself as someone who is interested in science.
20. Being informed about science is an important part of who I am.
21. In November 2024, who do you plan to vote for in the presidential election?
    a. Kamala Harris
    b. Donald Trump
    c. Robert F. Kennedy, Jr., if he were still running
    d. Jill Stein
    e. Cornel West
    f. Other
    g. I would not vote
    h. Not sure

Note on solar geoengineering portion:

The text we used to introduce solar geoengineering was based on Rosenthal et al. (2023). We present the texts from two other studies so that readers can compare them.

(a) This is the text that Rosenthal et al. 2023 included:
Solar geoengineering makes changes to the air or surface of the Earth to reduce the amount of sunlight that reaches the ground. One type of solar geoengineering that scientists are exploring is called stratospheric aerosol injection. Naturally, erupting volcanoes release gases into the upper atmosphere that block sunlight from reaching the Earth's surface. This can cool the planet. Based on that effect, scientists have proposed using high-altitude aircraft or balloons to release special gases into the atmosphere to help make the planet cooler. But there may be some problems with this solution. Some scientists think the release of the gases can harm the ozone layer. The gases may also harm ecosystems and agriculture. Finally, the gases can drift down to the lower atmosphere, which is where clouds form, and cause more acid rain.

(b) This is text from the survey by Mahajan et al. (2019), where respondents were randomly assigned one of the three treatments:

[Control] Some experts have proposed a new approach to limit climate change called solar radiation management or solar geoengineering. This approach would involve spreading particles such as sulfate aerosols in the atmosphere to reflect some incoming sunlight into space. By reducing the sunlight reaching the Earth, solar geoengineering would cool the planet.

[Nature:] Some experts have proposed a new approach to limit climate change called solar radiation management or solar geoengineering. This approach would involve spreading particles such as sulfate aerosols in the atmosphere to reflect some incoming sunlight into space. During the volcanic eruption of Mount Pinatubo in the Philippines, the sulfate aerosol particles that were naturally lofted into space led to global cooling of 0.9 degrees Fahrenheit (0.5 degrees Celsius). By reducing the sunlight reaching the Earth, solar geoengineering would cool the planet.

[Anthropogenic:] Some experts have proposed a new approach to limit climate change called solar radiation management or SRM. This approach would involve spreading particles such as sulfate aerosols in the atmosphere to reflect some incoming sunlight into space. Some factories have already emitted these particles as a byproduct of industrial processes (not for the purposes of cooling the atmosphere). By reducing the sunlight reaching the Earth, SRM would cool the planet.

Open-ended response analysis. Responses were examined by two coders based on nine categories derived from focus group and interview results: firm rejection, risky, unsure, chemtrails, solar power, impossible/expensive, nuanced support for research, strong support for research or deployment, and science fiction. Two coders completed two rounds of coding, each with 10% of the statements ($n = 300$) and achieved a high level of inter-rater reliability ($\kappa > 0.8$) for all nine categories. Thereafter, the remaining statements were assessed by one coder.

Hierarchical, linear regression analyses controlled for demographics, political ideology (1 = very liberal, 5 = very conservative, $M = 3.01$, SD = 1.16), interest in political news (1 = hardly at all, 2 = only now and then, 3 = some of the time, 4 = most of the time, $M = 3.18$, SD = 0.96), importance of religion (1 = not at all important, 2 = not too important, 3 = somewhat important, 4 = very important, $M = 2.6$, SD = 1.20), environmental identity (average of two items, I think of myself as someone who is concerned about the environment; Being environmentally friendly is an important part of who I am, averaged index: $M = 5.01$, SD = 1.43, alpha = 0.85), science identity (average of two items, I think of myself as someone who is interested in science; Being informed about science is an important part of who I am, $M = 5.05$, SD = 1.41, alpha = 0.87), belief in chemtrails ($M = 2.56$, SD = 1.31), and belief in atmospheric modification already happening ($M = 2.77$, SD = 1.16) as shown in Tables 1, 5 in the paper.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Survey data for this study can be accessed at: https://osf.io/eu793/?view_only=a11ed2a8d1334b9ba574d7fbcbd8523c.

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H.J.B., P.S., L.A., and J.Z.Y. designed research. H.J.B., P.S., L.A., and J.Z.Y. performed data analysis. All authors wrote and edited the paper.

Competing interests

The authors declare no competing interests.

Ethics

This study was reviewed and approved by the University at Buffalo IRB, STUDY00008639 (survey) and STUDY00006125 (interviews and focus groups).

Additional information

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