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Crutzen +10: Reflecting upon 10 years of geoengineering research

What do people think when they think about solar geoengineering? A review of empirical social science literature, and prospects for future research

Elizabeth T. Burns[1], Jane A. Flegal[2], David W. Keith[1,3], Aseem Mahajan[4], Dustin Tingley[4], and Gernot Wagner[1]

[1]Harvard John A. Paulson School of Engineering and Applied Sciences, Cambridge, Massachusetts, USA, [2]Department of Environmental Science, Policy, & Management, University of California, Berkeley, California, USA, [3]Harvard Kennedy School, Cambridge, Massachusetts, USA, [4]Department of Government, Harvard University Faculty of Arts and Sciences, Cambridge, Massachusetts, USA

Key Points:

- Empirical social science research on public views of solar geoengineering is methodologically diverse, focused mostly on the Global North
- Framing solar geoengineering poses a particular challenge, as the mere introduction of the topic can bias views
- Studies find some conditional—perhaps reluctant—openness to certain kinds of solar geoengineering research

Corresponding author:
G. Wagner, gwagner@fas.harvard.edu

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Abstract Public views and values about solar geoengineering should be incorporated in science-policy decisions, if decision makers want to act in the public interest. In reflecting on the past decade of research, we review around 30 studies investigating public familiarity with, and views about, solar geoengineering. A number of recurring patterns emerge: (1) general unfamiliarity with geoengineering among publics; (2) the importance of artifice versus naturalness; (3) some conditional support for certain kinds of research; and (4) nuanced findings on the "moral hazard" and "reverse moral hazard" hypotheses, with empirical support for each appearing under different circumstances and populations. We argue that in the coming decade, empirical social science research on solar geoengineering will be crucial, and should be integrated with physical scientific research.

1. Introduction

Crutzen [2006] has spawned a number of empirical social science studies on solar geoengineering, including peer-reviewed work that investigates public perceptions or that takes a more dialogic approach to engaging publics. These studies have distinct aims and methodologies, and scholars have warned against treating them similarly [*Burns and Flegal*, 2015; *Corner and Pidgeon*, 2015]. Nevertheless, these studies have reported various publics' views regarding solar geoengineering. Here, we review around 30 studies of wider public perceptions, including both deliberative and participatory approaches as well as experimental surveys, and highlight some cross-cutting themes. These themes do not represent all views, nor should they be interpreted as expressing the perceptions of a monolithic public.

Notably, the majority of this work has focused on lay public perceptions of geoengineering, with some exceptions: *Mercer* [2014] relies on surveys and interviews to suggest that perceptions of risk, uncertainty, and the "moral hazard" hypothesis inform the preferences of experts in climate science and policy, but the study's small sample of participants precludes generalization. Other expert surveys find a wide range of views and concerns, including those related to nontechnical issues [*Cairns and Stirling*, 2014; *Huttunen et al*., 2014], challenging binary distinctions between "expert" and "public" [*Winickoff et al*., 2015].

We build upon and update earlier reviews [e.g., *Corner et al*., 2012; see also: *Bellamy and Lezaun*, 2015; *Merk et al*., 2015] to highlight several common themes that can and should inform solar geoengineering discourse and research moving forward. This review also reveals potential gaps, especially with respect to the kinds of publics surveyed or engaged, and with research questions asked. Despite perceptions that social science research has "gotten ahead" of natural science research on solar geoengineering, this review suggests that more empirical social science on these questions, and others not yet investigated, is critical. Still, there are consequences to engaging in this kind of work, including the risk of prematurely locking in solar geoengineering as a climate policy option [*Stilgoe*, 2015] and bolstering an asymmetry in the analysis of climate science and policy more broadly [*Heyward and Rayner*, 2013].

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2. Common Findings in Empirical Social Science to Date

Earlier reviews of empirical social science work on solar geoengineering have identified several key themes across participatory and survey studies. *Corner et al*. [2012], in an early review, identify five key points in the literature on public perceptions from surveys of geoengineering: (1) low public knowledge; (2) people tend to distinguish between technologies when given a small amount of information, preferring carbon dioxide removal strategies; (3) people can and do discern between research and deployment; (4) people tend to prefer more conventional climate policies when comparing geoengineering in context with them; and (5) deliberative research indicated themes like naturalness, the reversibility of techniques, and the challenges of responsible governance.

Later reviews confirm several of these findings [e.g., *Merk et al*., 2015]. In what follows, we comment on some of these themes as well as others that have emerged from recent research. Specifically, more recent studies have called attention to the need to engage diverse, global publics, and have experimented with different approaches to deal with the problems associated with framing geoengineering. Research approaches and findings continue to evolve, and will likely continue to do so over the next ten years.

2.1. Unfamiliarity Remains

Research since *Corner et al*. [2012] suggests public awareness has not increased noticeably. As a baseline, the study of *Mercer et al*. [2011] finds in a survey of the United States, Canada, and the United Kingdom ($n = 3105$) that just 8% of respondents could accurately define "geoengineering," though they also find that more survey respondents (45%) could accurately define "climate engineering." The authors attribute this to the likelihood that respondents were "able to separately define climate and engineering" [*Mercer et al*., 2011, p. 4]. More recently, *Corner and Pidgeon* [2014] reports that 28% of participants in the United Kingdom have heard of "geoengineering," but "only 2% reported that they knew a fair amount or a great deal about geoengineering—a level of knowledge consistent with previous studies." *Merk et al*. [2015] reports that, in Germany, 20% have heard of stratospheric aerosol injection (SAI), while only 3% of those have heard "a lot" about it.

Confusion behind the details of solar geoengineering may also be behind one seemingly large outlier among surveys. *Sugiyama et al*. [2016] surveys university students from OECD countries (Japan, Korea, and Australia) and non-OECD countries (China, India, and the Philippines). Respondents from OECD countries report low awareness, while about 50% from non-OECD countries report knowing "a lot or a little about climate engineering." Given this surprising result, the authors caution that "a possible explanation is that the students thought of it as something different but related (e.g., artificial rainmaking or large-scale civil engineering)." There may yet be true differences in understanding across populations sampled, though the overwhelming consensus concludes that for many regions, familiarity with geoengineering remains low.

2.2. Framing Has Received More Attention

Unfamiliarity with solar geoengineering brings a key methodological challenge, since the mere introduction of the topic introduces potential bias [e.g., *Corner et al*., 2012; *Bellamy et al*., 2016; see also: *Fischhoff and Fischhoff*, 2001]. Framing can have a large influence on publics' perception of solar geoengineering. For example, research has shown that the perception of "naturalness" is a key driver of risk perception regarding emerging technologies [*Slovic*, 2000; *Pidgeon et al*., 2013]. *Corner and Pidgeon* [2015] tests this frame effect directly, finding that caution is in order "when using natural analogies to communicate about geoengineering with the general public, as frame choice is likely to influence public attitudes and potentially convey undue positivity." *Pidgeon et al*. [2013], meanwhile, concludes that geoengineering, by its very nature, "meant that natural systems would be interfered with" and that "there was no consensus about whether this was a good or bad thing."

To test whether participants would still consider "naturalness" as a key factor if the researchers did not introduce and frame the topic in such a way, *Bellamy et al*.'s [2016] deliberative study finds respondents still raise it "unprompted." These kinds of deliberative exercises, which seek to "open up" framings of geoengineering, allow participants to frame global environmental issues and climate change broadly, and evaluate climate policy options (including solar geoengineering) themselves [*Bellamy and Lezaun*, 2015; *Bellamy et al*., 2016]. Efforts at "unframing" solar geoengineering also seek to manage the problem of rendering geoengineering legible for public deliberation, while not prematurely locking it in as a policy option [*Bellamy and Lezaun*, 2015; *Stilgoe*, 2015].

2.3. Nuanced Views of Research and Deployment

Many of the studies reviewed here examine public views regarding solar geoengineering research. As noted by *Bellamy et al*. [2016] and *Macnaghten and Szerszynski* [2013], respondents' views are too nuanced to capture in binary terms such as "supporters" and "detractors." However, various publics are capable of distinguishing between research and deployment, and many suggest conditional — perhaps reluctant — support for the former [*Spence et al*., 2010; *Mercer et al*., 2011; *Pidgeon et al*., 2013; *The African Academy of Sciences*, 2013; *Beyerl and Maas*, 2014; *Winickoff et al*., 2015].

There are exceptions. Those who oppose research generally do so either because of concerns with potential risks of research itself, or with the notion of a "slippery slope" to deployment [*Merk et al*., 2015]. For example, one study finds that opposition to research resulted from a desire to "prevent negative consequences either from the research or from deploying technologies developed from it" [*U.S. Government Accountability Office*, 2011]. Another exercise finds that participants are "consistently skeptical" about the idea, "even of limited research" on solar geoengineering, possibly because "the effects [are] perceived by some to be knowable only in the context of full deployment" [*Macnaghten and Szerszynski*, 2013]. That study also finds that initial conditional support for research declines over time and with increased deliberation. This finding underscores that public views often evolve in deliberative contexts. Note, however, that here, too, researchers can introduce unintentional biases with new information, necessitating the need to be mindful of the framings and methodologies employed.

Conditionality is a key theme in most studies examining views on research. Any support for research often depends upon a variety of factors. For example, *Macnaghten and Szerszynski* [2013] identifies five conditions mediating public views regarding the acceptability of solar geoengineering: scientific robustness, research foreseeability, research efficacy, effective governance, and democratic conditions. It is worth noting that not all of these conditions depend upon physically defined thresholds. For example, trust in experts emerges as an important issue in at least three studies [*Macnaghten and Szerszynski*, 2013; *Merk et al*., 2015; *Winickoff et al*., 2015], as do concerns related to climate politics writ large, geographical inclusion [*Winickoff et al*., 2015], and issues of transparency and democratic accountability [*Macnaghten and Szerszynski*, 2013; *Pidgeon et al*., 2013; *Beyerl and Maas*, 2014; *Winickoff et al*., 2015].

Publics also make distinctions between the kinds of research they might support. Various studies find some support for indoor research, especially computer modeling [*The African Academy of Sciences*, 2013; *Beyerl and Maas*, 2014; *Merk et al*., 2015; *Winickoff et al*., 2015]. In an exercise with participants from the Global South, *Winickoff et al*. [2015] find that geographical inclusion in solar geoengineering research, even during early-stage laboratory experiments and modeling studies, is important for the credibility and support of research.

Moreover, outdoor research opens up additional questions around safety and risks, both for humans and for the environment [e.g., *Pidgeon et al*., 2013; *Winickoff et al*., 2015]. Some participants raise concerns about uncertainty and control [*Natural Environment Research Council*, 2010; *Macnaghten and Szerszynski*, 2013; *Wibeck et al*., 2015; *Winickoff et al*., 2015]; issues regarding reversibility [*Natural Environment Research Council*, 2010]; the need for appropriate regulation and/or oversight at various scales [*The African Academy of Sciences*, 2013; *Beyerl and Maas*, 2014; *Winickoff et al*., 2015], including perhaps a staged approach to research [*Natural Environment Research Council*, 2010; *The African Academy of Sciences*, 2013]; and multi-disciplinary collaboration [*Beyerl and Maas*, 2014]. Sources of funding for research also emerge as important in some studies, with some participants concerned with vested interests and/or private money in research [*Royal Society* (*Great Britain*), 2009; *U.S. Government Accountability Office*, 2011]. The possibility for these conditions to be realized should be an additional topic of research [*Macnaghten and Szerszynski*, 2013].

2.4. Risk and Uncertainty Are Important

Real and perceived risks play a key role in public debates on solar geoengineering [e.g., *Royal Society* (*Great Britain*), 2009; *Mercer et al*., 2011; *Pidgeon et al*., 2013; *Amelung and Funke*, 2015; *Winickoff et al*., 2015]. Complicating publics' concerns with risk are questions about systemic uncertainty and even "ignorance": participants often doubt whether scientists and societies can ever know enough to justify intervention. *Wibeck* *et al*. [2015], for example, finds some participants raising "doubts as to whether it was in principle possible to obtain enough knowledge to justify deploying [climate engineering] technologies." *Mercer et al*. [2011], too, finds the potential risks are important drivers of public perception, "with the most salient being damage to the ozone layer and unknown risks."

One overarching theme, however, is that risk and uncertainty of solar geoengineering need to be seen in the context of broader climate risks and uncertainties. For example, *Pidgeon et al*. [2012] report "significant positive correlations […] between concern about climate change and support for different geoengineering approaches." *Merk et al*. [2015], among several others, supports these findings. Placing solar geoengineering in the broader context of climate risk is particularly salient as uncertainty and outright "ignorance" have increasingly been acknowledged as part of the general climate policy conversation [*Summers and Zeckhauser*, 2008; *Weitzman*, 2009; *Pindyck*, 2012, 2013; *Convery and Wagner*, 2015; *Wagner and Weitzman*, 2015; *Wagner and Zeckhauser*, 2016]. These issues of ignorance, "unknown unknowns," and systemic uncertainty figure centrally in discussions of the risks of solar geoengineering research and deployment. In addition, one prominent nonphysical risk centers on notions of "moral hazard."

2.5. "Moral Hazard" Competing With Inverse Hypothesis

The so-called moral hazard of solar geoengineering, the fear that mere talk or research of solar geoengineering might lead to less mitigation, has arguably been one of the key detractors discouraging research into the subject. *Keith* [2000] has introduced the term to the discussion. Technically, the term itself is incorrect, as it typically applies to adverse incentives between two parties. Instead, it might be better understood as a "lack of self-control" [*Wagner and Weitzman*, 2015, p. 197] or as a "moral responsibility" issue — that solar geoengineering research might be seen as "an intervention in the ongoing ethical debate about proper remedies for climate change" [*Winickoff et al*., 2015, p. 631].

Still, the "moral hazard" notion is well-founded theoretically [*Reynolds*, 2014], though it goes up against a directly competing hypothesis, what one might loosely call the "reverse moral hazard," often taking one of two forms: (1) Tversky and Kahneman's [1973] "availability heuristic" arguing that talk of solar geoengineering makes climate policy in general more salient or (2) that solar geoengineering itself is seen as such a threat that it would lead to greater desire to mitigate. Only empirical analysis can decide which theory best captures reality under which circumstances.

The latest empirical research on public understandings of solar geoengineering makes clear that the risk of "moral hazard" is a concern for various publics. In a section titled, "Treating the symptoms rather than causes of climate change," Wibeck et al [2015, p. 27] note how study participants liken geoengineering to a "sign of surrender" or a "panic action." Acknowledgment — and even fear — of the potential for "moral hazard" is widespread [e.g., *Beyerl and Maas*, 2014; *Amelung and Funke*, 2015; *Wibeck et al*., 2015; *Bellamy et al*., 2016].

Yet, despite the concern that society — *other* people — would have less incentive to mitigate once they have knowledge of solar geoengineering, "moral hazard" often disappears and even reverses when studied at the individual level. *Merk et al*. [2016], for example, finds people are more willing to offset their own emissions when they receive information about solar geoengineering. The authors attribute this behavior to subjects viewing solar geoengineering as a potential "threat" and, thus, "increase mitigation to prevent a level of climate change that would make the deployment of SAI more likely." Others attribute the finding of "reverse moral hazard" to an increase in concern for climate change, sparked by learning about solar geoengineering [*Kahan et al*., 2015].

Neither type of response is universal. More skeptical publics and those endorsing "self-enhancing" values are more likely to fall into the "moral hazard" camp [*Corner and Pidgeon*, 2014]. For some, knowledge of solar geoengineering may reduce incentives to mitigate; for others, such knowledge may solidify preconceived notions of the importance of climate policy action. Revealed-preference studies following *Merk et al*. [2016] and deliberative exercises may provide our best hope to identify the context necessary for "moral hazard" or its inverse to emerge empirically.

2.6. Research Remains Geographically Limited

Most studies to date have focused on the Global North, and not on populations particularly vulnerable to climate change. Exceptions include *Winickoff et al* [2015] and *Carr* [2015], and work in the grey literature such as reports from workshops held in Fiji [*Beyerl and Maas*, 2014] and by the Solar Radiation Management Governance Initiative. Other than *Carr* [2015], who engages Alaska Natives, few studies have worked with indigenous groups. *Whyte* [2012] offers an introduction to this topic.

So far, efforts in the Global South tend to engage more expert-level publics than laypeople. One reason for this is that recruitment for most of the surveys and some of the deliberative work has been via professional firms, which likely do not operate in these areas. Moreover, empirical work requires linguistic and cultural competencies; expert-level respondents in the Global South have in effect been doing "translation work." Partnering with institutions and researchers in the Global South will be necessary to begin co-defining a research agenda, learning what questions to ask, and what is important to different communities. This work has scarcely begun.

3. The Path Forward

At present, public engagement with geoengineering is still something of a quixotic endeavor: many strategies are untested. Given the plethora of social problems we face, is it even justifiable to spend research funds—particularly public research funds—on a set of technologies in the conceptual stage? Early empirical social science suggests that discussing solar geoengineering may influence how people think about climate change in general [e.g., *Kahan et al*., 2015]. Moreover, discussing solar geoengineering could itself be considered an experiment in exploring broader sociological questions about public engagement with future technologies and environmental decision-making [*Jasanoff*, 2015; *Stilgoe*, 2015].

Yet, perhaps the most compelling reason for an empirical social science program is that early research could mitigate future risks: this argument is often made in support of research in the natural sciences, but it applies to social science as well. Publics' awareness of solar geoengineering is crucial for an informed, deliberate conversation [*Keith*, 2013; *Morton*, 2015]. *Not* pursuing empirical research on a subject like this comes with direct risks. Rigorous peer-reviewed science can provide a much-needed corrective to the proliferation of false claims about what the publics do or do not want. Upstream public engagement and deliberation is crucial to prevent decisions made on untrue or poorly-thought-out premises [*Burns and Flegal*, 2015].

The type of research matters tremendously, as research can perform a legitimizing or performative role [*Bellamy and Lezaun*, 2015] or shape the public response to geoengineering technologies rather than reflect it [*Heyward and Rayner*, 2013; *Stilgoe*, 2015]. Sociological research needs to self-consciously mitigate these risks.

A healthy social science research agenda into geoengineering would do the following:

(1) Include mixed methods, in which qualitative and quantitative research is synthesized rather than conducted ad hoc and separately. It would experiment with and develop new methods appropriate to investigating speculative or future scenarios; as "it will be necessary to develop techniques and skills to imagine the composition of a geoengineered future that might be brought into being through solar radiation management—its phenomenology, its political economy, its lifeworld" [*Macnaghten and Szerszynski*, 2013].

(2) Engage with publics in the Global South and more diverse groups within the Global North, while also standardizing methodologies to make results comparable across publics.

(3) Expand the scope of research to understand attitudes and perceptions among communities of experts engaged in the study of solar geoengineering, such as policymakers, political scientists, advocacy groups, and climate and environmental scientists.

(4) Continue to bridge disciplinary boundaries, and incorporate disciplines within social sciences, such as human geography or anthropology, and economics or political economy. The latter would imply a move toward experimental and revealed-preference methods, whereas the former would imply more deliberative and dialogic formats.

(5) Embrace both descriptive and empirical as well as constructive methods. The latter, in form of "participatory technology assessments" can be used to "improve the outcomes of science and technology decision-making through dialog with informed citizens" to enable them to have a voice in research decisions [*Tomblin et al*., 2015].

(6) Pursue new and understudied lines of research and link them to current public policy questions. How can indigenous and vulnerable populations be included in decision-making? Where do people get information about solar geoengineering, and how do they use it? How much do geography, gender, class, or race inform people's attitudes? What other contextual factors—a retreat from globalization, growth of other controversial technologies—shape perceptions? How do religious communities interpret the idea? How do conspiracy theories around so-called "chemtrails" impact public views? Another decade also brings new opportunities for longitudinal studies.

Empirical social science can be time consuming, expensive, and messy. However, social science research into the ethical, political, and social questions associated with climate change itself, and with geoengineering in particular, can and should proceed. Embarking on research itself needs to be done with care to avoid experimenter's regress on the one hand and technological lock-in on the other [e.g., *Jasanoff*, 2015; *Stilgoe*, 2015; *Juma*, 2016]. Nevertheless, rigorous international and multidisciplinary research could help produce robust and democratically-accountable knowledge about geoengineering and climate policy more broadly.

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