‘Bog here, marshland there’: tensions in co-producing scientific knowledge on solar geoengineering in the Arctic

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Abstract

Solar geoengineering has been suggested as a means to cool the planet and ameliorate climate impacts in the Arctic. However, few studies approach this idea from the viewpoint of Arctic communities. We explore the substantive rationale for public engagement with solar geoengineering research, including the premises that: (a) evaluation of local impacts by communities can generate better knowledge about what modeling results mean; and (b) ideas and questions surfaced in public discussions can contribute to and shape scientific research. We convened focus groups in Finnish Lapland, conducted scientific analysis of climate model output on albedo modification based upon the discussions, and returned a year later to discuss the results. The increased granularity of scientific information highlighted the limited scientific basis for decisions, which turned the discussions back towards questions of ethics and justice. We conclude that while there are serious limitations to global public decision-making on climate intervention, in the absence of formal governance, co-producing research could act as one de facto form of governance.

1. Introduction: Arctic communities as research ‘subjects’ when it comes to climate engineering

The Arctic is warming more rapidly and dramatically than elsewhere. The extreme changes in the Arctic will be felt all over the world as ice melt amplifies the warming effect of CO\textsubscript{2}—and other tipping points such as permafrost and clathrate melt threaten to accelerate climate change globally (AMAP 2017b, 2019, IPCC 2019, Lenton \textit{et al} 2019). These rapid, non-linear changes with global implications have been brought up as reasons for researching solar geoengineering in the Arctic (Caldeira and Wood 2008, Moore \textit{et al} 2014, Tilmes \textit{et al} 2014, MacCracken 2016). Reducing the amount of incoming sunlight could slow sea ice melt and prevent tipping points. Climate model simulations have also suggested that it may be possible to use regional albedo modification in the Arctic to reduce the amount of climate change, although there would be residual changes (Tilmes \textit{et al} 2014, Jackson \textit{et al} 2015). There have been a few different strategies proposed for how to go about geoengineering the Arctic—injecting aerosols into the stratosphere, brightening marine clouds, ice sheet conservation, or even refreezing ice (Desch \textit{et al} 2017, Field \textit{et al} 2018, Moore \textit{et al} 2018, 2021, Bodansky and Hunt 2020, Lee \textit{et al} 2021). Given this speculative research, political scientist Corry (2016) has argued that ‘the Arctic has become a site of virtual geoengineering experimentation and intervention,’ tracing the history of this interest back to Cold War times.

Yet what people who actually live in the Arctic think about Arctic climate invention is largely unknown. One interview-based study with Alaska Natives found a deeply reluctant acceptance to consider it, with severe reservations and concerns,
including around how it would be controlled (Carr and Yung 2018). In Buck’s (2018) interview-based study in Finnish Lapland, locals discussed the implications of geoengineering from cosmopolitan perspectives rather than Arctic or local interests, though their thoughts about it were informed by particular local and regional histories. The circumpolar Arctic, with its four million inhabitants across eight nations and Indigenous peoples, has been cited as a region with prospects for cooperative governance of rapid environmental and socioeconomic changes. At the same time, there is the potential for widely divergent interests within the Arctic when it comes to climate intervention. Arctic communities’ exposure and vulnerability to impacts of climate change varies between different parts of the pan-Arctic region (see AMAP 2017a, 2017c, 2018). Factors such as infrastructure, education level, livelihood structure, and even political-administrative and planning culture may influence the adaptive capacity of communities (Knieling and Othengrafen 2009, Juhola et al 2012).

For some Arctic (sub-)regions/communities, like Finnish Lapland or Greenland, climate change may also have positive impacts (Mettiäinen 2013, AMAP 2018). Moreover, what governments and private sector or civil society stakeholders see as optimal may diverge from the varying desires of publics.

As there will likely be no singular ‘Arctic view’ on climate intervention, public engagement with local communities in different parts of the Arctic is recognized as vital. Few studies have been conducted so far, but it is plausible that views on geoengineering may vary between Arctic communities as do the impacts of climate change and adaptation needs to them, as the recent AMAP reports highlight. Public perceptions of solar geoengineering and strategies for inclusive, meaningful societal engagement are highlighted in the recent recommendations on solar geoengineering research and its governance by the National Academies of Sciences, Engineering, and Medicine (NAS 2021). Many scholars have cited public engagement as a desirable for governance of climate intervention and the process of developing it (Rayner et al 2013, Burns and Flegal 2015, Frumhoff and Stephens 2018, Hubert 2021). In fact, the 2021 cancellation of a balloon flight in Sweden, which would have tested equipment to be used in future experiments but which faced opposition from environmentalists and representatives of northern Scandinavia’s Indigenous Saami communities (Nature 2021), highlights the risks of failing to engage with publics on solar geoengineering research.

Indeed, there have been several attempts at ‘upstream engagement’ with climate engineering (Corner et al 2012). These are helpfully reviewed by Bellamy and Lezaun (2015), who have characterized deliberative upstream engagements as having two ‘waves.’ The first wave was encompassed in the 2010 Experiment Earth dialogue, a series of workshops which formed geoengineering as a discrete, known object of deliberation. A second wave of public engagements aimed to ‘unframe’ geoengineering: to unsettle assumptions, and allow for a diversity of approaches and framings of climate engineering to avoid ‘locking in’ geoengineering as a concept, and to avoid having public engagement reify geoengineering as a tangible technological future (Bellamy and Lezaun 2015). Strategies for ‘unframing’ included asking respondents to consider geoengineering alongside mitigation and adaptation, or other broader considerations about climate and social and political systems, as well as consciously exploring different frames (Bellamy et al 2013, Macnaghten and Szerszynski 2013, Wibbeck et al 2015, Asayama et al 2017). Many of these studies strove to generate knowledge of how publics think about solar geoengineering research, stemming from a normative rationale, with some attempts to also create knowledge on public perceptions, concerns, and critical questions that would be relevant to policymakers in shaping climate intervention governance and national stances on it. In general, some of the outputs of these can be seen as co-production of knowledge about governance of climate intervention research.

Here, we are interested in incorporating public ideas, questions, and concerns into the scientific research process itself. There are varying rationales for public engagement, from the instrumental to the substantive to the normative (see Fiorino 1990), and in this case, we are interested in a substantive rationale: ‘Could deliberative activities which incorporate publics into the research process produce better science on questions of public interest—new discoveries from seeing the problem a different way, or more socially relevant science—as well as allow publics to shape the research agenda?’ To our knowledge, this is the first study on co-producing scientific knowledge on geoengineering with community members. Our focus on co-production has been informed by both literature and codes of conduct in Arctic (social) sciences on participatory and ethical research, which emphasize the need to consult Arctic communities for research questions relevant for them for solving complex sustainability challenges, provide meaningful learning experiences as a part of the research process, and then return to the field sites with the results (e.g. NSF sa., Petrov et al 2016, IASSA 2020), codes of conduct for research on geoengineering (The Royal Society 2009, p 42, Hubert 2021), as well as the burgeoning literature on public deliberation on emerging technologies.

2. Methods

We used a three-phase design to examine how public ideas could be incorporated into solar geoengineering research. First, we held public lectures and focus
groups in two municipalities in Lapland, the northernmost region of Finland, in August 2016; second, analysis of modeling results was conducted; and third, in October 2017, focus groups were convened again.

2.1. Site characteristics
Stretching between 65 and 70 degrees Northern latitude, Lapland is located mostly north of the Arctic Circle. Lapland is sparsely populated, with approximately 180 000 residents. The main livelihoods include tourism, forestry, mining, reindeer herding, manufacturing, and public services including health care and education. The focus groups were held in Rovaniemi, Lapland’s regional administrative and commercial center or ‘capital’ with a population of about 60 000, and Sodankylä, a mostly rural or wilderness-like municipality of about 8500 residents 130 km to the north from Rovaniemi. The northernmost part of Sodankylä municipality belongs to the Home Region of the Saami people, the only Indigenous people in the European Union. Saami people live also in Rovaniemi. None of the participants mentioned having an Indigenous background, and it was not asked about in the focus groups.

2.2. Recruitment and focus group protocol
Recruitment to the focus groups was made by press releases, through social media of the University of Lapland, and emails to representatives of key industries, public services/offices and NGOs and to people who had been active in climate matters; it was not topic-blind. Recruitment of participants in the second round was similar to the first round, except that the participants of the first round were contacted directly by emails based on the contact information they gave in their research consent forms; about half the participants were repeat attendees (focus groups, participants n = 8 and 6 in 2016; n = 3 and 5 in 2017). Both rounds of deliberative engagement had a similar program. First, public lectures for a wider audience were held which discussed global, Arctic, and Lapland-specific societal impacts of climate change6, and albedo modification, focusing on stratospheric aerosols (with Q&A, these were about 1 h each). Then, focus group participants came together and spent one hour in discussion (see supplementary information available online at stacks.iop.org/ERL/17/045001/mmedia). The public lectures were held in English, with Finnish translations available; the focus groups were held in Finnish. The first-stage interview protocol began with questions on observed climate impacts, in order to ‘localize’ the discussion, and transition from the Q&A from the public lecture. While asking specific questions about climate change impacts invited people to ground themselves in a local perspective, this could also influence their assessment of climate intervention. This was deliberate, as we aimed to produce knowledge that would be locally interesting or relevant. The next part of the interview protocol emphasized questions about climate intervention that publics wanted more information about, or that would be helpful for them in assessing this approach. In the second round of focus groups, the public lectures and focus groups included discussion of the modeling output analysis, as well as self-reflective questions on the research setting. The interview transcripts were translated from Finnish to English and then thematically coded by two authors.

2.3. Methodological challenges
One methodological challenge is that public lectures were useful in informing participants, but inevitably framed the material to be discussed. The public lectures allowed the publics to have an extended Q-and-A session with experts, which was critical because many people were not familiar with solar geoengineering. Inevitable limitations of this include the potential for bias of information provided, a focus on information that the expert found relevant, and the fact that this is not a manner in which most people are introduced to the topic. We attempted to mitigate framing effects by having the presentation reviewed by several people and pilot tested with groups of students who were asked to reflect on the information presented, including if seemed to have bias. A second methodological challenge was the low number of participants in the second-round focus groups a year later, which risks having insufficient breadth of perspectives offered. Moreover, our respondents were non-representative; the participants brought expertise from their own fields to bear on the issue, blurring the distinction between expert and public. While our focus group participants were members of the local community, many of them even born in the region, having thus also experience based and possibly traditional knowledge on climate and environment in the region, many of them had also scientific or other

6 The negative impacts or potential threats of climate change to Lapland are largely related to hydrospheric and cryospheric changes. Post-glacial rebound in the Bothnian Gulf of the Baltic Sea will neutralize sea-level rise at least until year 2050. Precipitation is expected to increase due to climate change, but its impact on flood risk is uncertain. Six settlements including Rovaniemi are flood risk sites. 20%–30% decrease in snow cover days and delay of natural snowfall can harm winter tourism in some decades, however less than in some competing destinations. Freezing and thawing cycles may reduce traffic safety and make it difficult for reindeer to dig lichen from under the snow. Longer growth season improves conditions for agriculture and forestry, but winter-time logging may become difficult if the ground does not freeze properly. Also new business opportunities are anticipated at the ice-free Arctic Sea year 2030 onwards (Finnish Meteorological Institute 2010, Regional Council of Lapland 2011, Miettäinen 2013, Gregow et al 2021).

7 See Winickoff et al (2015) for a discussion of the expert/public distinction.
professional expertise on climate change. In some ways, they were treated as a ‘concerned group’ or part of a learned collective (Callon 1999), where each had scientific/professional and/or local experience-based knowledge of climate change specific to their geography which was crucial to the production of new knowledge. This may have been a result of the recruitment, which openly invited any local community members in Rovaniemi and Sodankylä to participate in the public lectures and the focus groups; it is unsurprising that those with experience in climate change would have been most motivated to participate.

3. Results

3.1. First round of deliberative engagements: controllability, governance, and justice

The first round of discussions centered on three themes: (a) concerns about the controllability of solar geoengineering, (b) governance, and (c) justice and ethics. First, participants were concerned about ecosystem complexity and unexpected effects, as well as social control of the technology, which are prevalent concerns in other studies (Pidgeon et al 2013, Wibeck et al 2015). In the Sodankylä focus group, the immensity of the impacts of geoengineering was compared and associated with Soviet nuclear tests in the nearby Russian Arctic in the 1960s, which caused environmental impacts and potential negative health effects in Lapland. Concern was also expressed over the decision-making processes and the distribution of harmful impacts—the Soviet nuclear tests were also done without consent of or informing people in Lapland.

Participants were concerned about democratic governance of climate intervention. The participants saw clearly that they were not the people that would decide on deployment of solar geoengineering; some opined that power and interest groups would decide, and ‘money talks’. Yet these skeptical comments about the decrease of global governance capacity or the weakness of the United Nations were juxtaposed with more optimistic comments about how the world could or should be. One participant pointed out that while half the countries in the world are already outside of democratic decision-making, it would take a fortune to monitor geoengineering elections and bring knowledge to every human being on Earth: ‘So that’s all utopian in my opinion, and yet it is a thing that influences’ (Rovaniemi focus group 2016).

Concern was expressed over whether the inhabitants of the Arctic would actually have a ‘say’ on decision-making on climate intervention in the Arctic both in national and global contexts, if a popular vote on solar geoengineering deployment would be organized: if the 4 million Arctic inhabitants dispersed in eight countries was contrasted with the global population of 8 billion, or in a national vote, as the <180 000 inhabitants of Lapland represent only less than 4% of Finland’s population. Would Arctic inhabitants’ voices be heard, and what would be justice? As one participant asked, ‘There’s an interesting viewpoint, a question of basic rights, that can I as the region’s inhabitant decide on actions/interventions subjected to this region in the decision-making? [1] In a situation like this I probably cannot, because we represent such as small part of the global population.’ (Sodankylä focus group 2016)

3.2. Second round of deliberative engagements: cautions about modelling results as ‘a truth carved in stone’

We also talked with the first round of focus group participants about what their interests were in terms of climate impacts in Lapland; these included the impacts of climate change on winter quality and duration in Lapland, including snow (time of arrival, snow depth); temperature (especially summer month temperatures); and cloud cover. Snow conditions and summertime temperatures are weather and climate related factors that the success of reindeer (Rangifer tarandus tarandus) herding depends on (Turunen et al 2016, Rasmus et al 2021), which is an important livelihood to many in the region, including to some of the Indigenous Saami people. To look at how these parameters would change in Lapland under climate change and climate geoengineering, plots were generated using climate model output from the Geoengineering Large Ensemble (GLENS; Tilmes et al 2018a).

When returning to the two communities to conduct focus groups in 2017, plots on the impacts of albedo modification by stratospheric aerosol injection in Lapland, the circumpolar Arctic and in Helsinki (and plots on ozone loss and where the particles would land) were also provided; several examples are shown below. Many prior simulations of stratospheric aerosol geoengineering added aerosols only at the equator or in the tropics; this results in ‘undercooling’ of the high latitudes relative to the tropics. In the GLENS simulations, aerosols were added at multiple different latitudes to avoid this, and (mostly) restore high-latitude temperatures back to some reference condition, chosen in these simulations to be the average conditions over 2010–2030. While there was a plan to evaluate changes in the GLENS simulations more generally, analysis here looked at variables that would not otherwise have been considered without the feedback from the 2016 discussions.

In these model simulations, it would be possible to mostly annul the changes expected to take place in Lapland because of climate change, when it comes to 8 The northernmost part of Sodankylä municipality belongs to the Home Region of the Saami people, the only Indigenous people in the European Union. Saami people live also in Rovaniemi. However, none of the participants mentioned having an Indigenous background, and it was not asked about either.
variables like temperature, snowfall, and snow depth. However, there would still be some residual warming in the winter (but still well below freezing in Lapland); one reason for this is simply that geoengineering cools by reflecting sunlight, and there is more sunlight in summer than winter (Jiang et al. 2019). Despite the relatively warmer winter, snowfall and snow depth in these simulations are mostly similar to current conditions in Lapland. Cloud cover was another variable noted in 2016; this remained relatively unchanged; and summer precipitation (of relevance to flooding) is restored back to current levels. One key observation is that it is impossible to only cool the Arctic; trying to cool the Arctic results in at least some amount of global cooling (e.g. Tilmes et al. 2014). The GLENS simulations suggest that with the injection latitudes chosen there, it would be difficult to preferentially cool the Arctic relative to the tropics using stratospheric aerosols. Higher-latitude aerosol injection strategies have not yet been adequately explored (e.g. Jackson et al. 2015, Lee et al. 2021), and would provide greater cooling at high latitudes, but still with at least hemispheric effects; also note that significant cooling of the Arctic would also require cooling the Southern hemisphere in order to avoid risks for tropical climates posed by asymmetric single-hemisphere interventions (Jones et al. 2017).

In short, early discussions about regionally modifying Arctic climates by solar geoengineering may be misleading. The shift in the seasonal cycle of temperature at high-latitudes is another important observation that was highlighted as a specific result of focusing on the questions asked in 2016, and that has motivated subsequent research (Jiang et al. 2019), in contrast to many prior analyses of geoengineering that focus primarily on annual-mean quantities. The relatively warmer winter (though still much cooler than without climate intervention) is likely to have some consequences in Lapland, and may have more severe effects in regions where the winter temperatures are currently much closer to freezing.

In the second round of focus groups, participants had divergent responses to the presentation of the climate model output. The presentation of the output, as shown in figure 1, uses a set of simulations that compares a worst-case climate change scenario with
a best-case implementation of solar geoengineering, exaggerating both; this was discussed with participants. In the plots, only one worst-case climate change future is portrayed, making it appear as a singular climate change future. On the one hand, the modeling outputs made the prospect of solar geoengineering seem more real. On the other hand, even with this strong framing of best-case solar geoengineering vs. worst-case climate change, this ‘expert public’ was well able to identify the provisional nature of the information, and saw that the uncertainties of climate models are multiplied when it comes to climate intervention. Moreover, the knowledge base was also questioned in terms of how many people are creating the knowledge: as one participant pointed out, maybe a few dozen or a few hundred people study geoengineering, while climate change is studied by tens of thousands, and it is still not known how Lapland’s snow cover will change (Rovaniemi focus group 2017). People felt that the plots provided in the second round in 2017 answered some of their questions, but still a lot of research was seen to be needed on the topic before deployment of solar geoengineering could even be considered. On the level of values, ethics and maybe to some extent also emotions, most participants seemed convinced (more so than during the previous year) that geoengineering by atmospheric particles should not be deployed since it could bring so much harm for others, while in Lapland neither the impacts of climate change nor geoengineering would be very harmful.

The high scientific literacy of the focus group participants led to critical discussion on the use of plots and numbers as ‘truth’ strategies in today’s world, including political decision-making. One participant commented that ‘in a way, the results looked rather beautiful,’ and another commented on how using visual presentations and quantifications often tend to ‘become a truth carved in stone … In people’s minds they very quickly turn into something very certain,’ acknowledging while there might not be a better way of showing the results of our modelling work besides plots, ‘if you put there a number, it becomes certain. Then that number is referred to for justifying that this is how it is, even if, in fact, if put in words it is something else (…) There’s the danger that we lose the sense on what kind of issues we deal with… Especially if you present this to politicians.’ (Rovaniemi 2017).

Interestingly, in the second round of the focus groups, solar geoengineering was seen not so much as a design problem but as a global ethical concern. Between the two rounds of focus groups, the discussion seemed to turn from methods and design talk to ethics talk. In this sense, the plots did not answer the questions the focus group wanted to address on the second round. Models do not really respond to questions on ethical issues. After being presented the plots, the participants wanted to talk about the global impacts and side effects that solar geoengineering would have, and the balance between their needs and the needs of those already suffering more. Participants expressed shared guilt on having caused climate change and saw that ‘while others are dying, it would feel petty to worry about aspects like the prospects of winter tourism development’ (Sodankylä focus group 2017). The consequences of both climate change and geoengineering in Lapland were seen very mild and tolerable as compared to floods and hurricanes in the global south. It was clearly expressed that solar geoengineering ‘should not be done on our account’, if it means increased suffering for others already expected to face life-threatening impacts of climate change. This reflects the findings of Buck (2018). Many of the participants saw geoengineering as the last chance and only to be deployed as the last option. ‘There are so huge risks involved. (…) Bog there, marshland here. (…)’ If we are in such a lousy situation, that the only option is to try something this risky, I guess it is starting to be game over. I have a gut feeling, that as much as we should believe in technology, this sounds like shocking’ (Rovaniemi 2017). However, discussing solar geoengineering as a climate intervention approach seemed to give license to explore other large-scale environmental modification projects that might be more desirable, such as massive afforestation or other carbon dioxide removal approaches such as direct air capture. Nevertheless, mitigation was prioritized by the participants.

4. Discussion: the substantive case for public engagement in the research process

When considering the substantive rationale for co-production of research—to improve the quality or social relevance of the science via discussion with stakeholders or other relevant audiences—this pilot had some influence on the decision making of participating scientists post-engagement. The public deliberations in these two communities shaped some scientific research, eventually, though not necessarily in a linear way. First, the modeling team conducting the research altered what variables they analyzed and in terms of their awareness of what variables people might find relevant. For example, in addition to looking at specific regional climate variables that might otherwise not have been considered, this study influenced new investigation on how solar geoengineering might impact the seasonal cycles at high latitudes (Jiang et al 2019). In addition, the process of engaging with Arctic stakeholders influenced one of the scientific team to generate a new solar geoengineering scenario in which decision making is driven by Arctic politics first and could have different physical outcomes than those found in the more globally-minded simulations conducted to date (Dove et al 2021).
Elaborating on the idea that solar geoengineering would be done for saving the Arctic—either for global reasons or for the Arctic itself, as e.g. Corry (2016) has written about, it is also possible that the science generated from this will not have much impact, given the sense some respondents had that decisions about climate engineering would be triggered and shaped by events like food crises in the global south, with the Arctic and Lapland on the periphery.

As Braun and Konniger (2018) ask: ‘If (…) there is no connection between participatory arrangements and processes of scientific governance, what have the participants of these arrangements actually participated in?’ The question here is not simply how stakeholders and publics can be involved in the production of knowledge, but how can they be involved in the production of knowledge which will go on to shape policy?

Co-producing research on climate intervention has the potential to help create knowledge about locally relevant impacts of climate change and climate geoengineering—if there are mechanisms for using the knowledge in decisions about further research and policy. This preliminary study illustrates what’s at stake concerning solar geoengineering. If solar geoengineering proposals can be at least partially tailored to modify outcomes, then studies such as this would need to be replicated in places across the globe in order to understand what the different outcomes of albedo modification might actually be.

In particular, it could be valuable to repeat this study in several Arctic locations in order to more comprehensively identify ‘Arctic’ perspectives, given the heterogeneity of the region and the possible lack of people’s identification with the ‘Arctic’ as a concept. A diversity of Arctic locations could furthermore highlight differences in opinion across the Arctic, potentially disrupting or at least complicating the idea of ‘the Arctic’ as an object of global governance and also setting questions on the role of regional organizations such as the Arctic Council in climate matters9. Another approach could be to invite publics to co-design a research agenda on eventu- alities that should preclude climate intervention by any means including stratospheric aerosol injection or targeted intervention methods from further consider- ation, and then have scientists focus research on whether those scenarios are possible, or to invite pub- lics help prioritize research areas.

Interestingly, if one considers this example of co-production from an instrumental standpoint—which we consciously avoided doing, but some pub- lic engagement research on emerging technologies arguably falls within this rationale, often working with what Chilvers and Kearnes (2015, 2019) call a ‘residual realist’ imaginary of participation—this kind of study in fact seems poised to frustrate instru- mental aims. The effect of providing new scientific information, of maps and numbers, had the effect of both highlighting how limited the information upon which to make decisions currently is, and hence turn- ing the discussion from design talk to ethics talk. As McLaren and Corry (2021) point out, it is often assumed that more research would decrease uncer- tainty rather than increase or redistribute it. Here, more information did not increase certainty or con- fidence in the approach; it was quite the opposite. This case offers a caution against instrumental deliberations aiming to create consensus or social license.

Indeed, a concerted effort towards co-producing knowledge might eventually move away from the primacy of models and could change what ‘knowledge about climate intervention’ signifies. The primary challenge here is that in order to incorporate people’s ideas into the scientific process, the model- ers on our team needed metrics that could be incor- porated into analysis of climate model output. In general, these parameters are not terms that people think in—not even when they are scientifically literate audiences, as our respondents were. The narrowness of identifying specific parameters that scientists can analyze is in tension with some of the tendencies to broaden the discussion towards deeper questions of how we should or could be living, given what we know about climate change, and the ethical aspects of design and governance of climate intervention. Parti- cipants were interested in exploring justice concerns, such as the asymmetry of causing climate change and suffering from it, uneven impacts of climate engineer- ing, and the uneven power to make decisions about it. It is possible that further co-production attempts might move research further in this direction. Yet a key takeaway from this study is that genuine co- production cannot be achieved by simply analysing experiment results after talking to new groups of stakeholders. Rather, the engagement has to be done at the earliest stages of experimentation, when model- ers are designing the simulations that will be run, as also McLaren and Corry (2021) have noted.

If the normative rationale for public engagement with decisions around a global intervention like solar geoengineering might be impossible to fully satisfy—having participation from everyone in the globe—substantive engagement in the research might be the next best thing that works towards this normative rationale, if, in fact, co-producing scientific research

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9 While the Arctic Council plays a significant role in Arctic environmental protection and has continued as a platform for regional cooperation, it has not yet taken any stance on the role in the governance of geoengineering. Even if the Arctic Council hasn’t engaged in climate change mitigation work with a joint program, Arctic Council working groups have produced high level synthesis reports and scientific assessments on the impacts and drivers of climate change and on climate change adaptation and resilience in the region. The assessment reports—and lately the Framework on Black Carbon and Methane—have supported also climate change mitigation efforts of the Arctic Eight. In our study, the Arctic Council was not suggested by the focus groups as an organization that could represent the Arctic in geoengineering governance.
also aims to ‘create new forms of governance that produce both the knowledge necessary to achieve sustainability and the social dynamics to act on it’ (Miller and Wyborn 2018). In the absence of formal governance, climate engineering already experiences forms of de facto governance, as Gupta and Moller observe; right now, de facto governance of climate engineering happens in forms such as authoritative assessment reports that normalize and institutionalize the field (2018). Recognizing that, co-producing research could be a way of shifting this de facto governance a bit towards something more participatory. At the least, co-producing research could make it more likely that whatever design of climate intervention is up for deliberation by global elites has already been shaped by multiple communities and values.

**Data availability statement**

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request. Data used in generating figure 1 can be found at [https://www.cesm.ucar.edu/projects/community-projects/GLENS/](https://www.cesm.ucar.edu/projects/community-projects/GLENS/) (Tilmes et al 2018b).

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**References**

AMAP 2017a Adaptation actions for a changing Arctic: perspectives from the Barents area (Oslo: Arctic Monitoring and Assessment Programme (AMAP)) pp xiv + 267

AMAP 2017b Snow, water, ice and permafrost in the Arctic (SWIPA) 2017 (Oslo: Arctic Monitoring and Assessment Programme (AMAP)) pp xiv + 269

AMAP 2017c Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region (Oslo: Arctic Monitoring and Assessment Programme (AMAP))

AMAP 2018 Adaptation Actions for a Changing Arctic: Perspectives from the Baffin Bay/Davis Strait Region (Oslo: Arctic Monitoring and Assessment Programme (AMAP))

AMAP 2019 Arctic climate change update 2019. An update to key findings of snow, water, ice and permafrost in the Arctic (SWIPA) 2017 (Arctic Monitoring and Assessment Programme (AMAP)) [available at: https://oaarchive.arctic-council.org/bitstream/handle/11374/2553/ccupdate18.pdf?sequence=1%26isAllowed=y](https://oaarchive.arctic-council.org/bitstream/handle/11374/2553/ccupdate18.pdf?sequence=1%26isAllowed=y)

Asayama S, Sugiyama M and Ishii A 2017 Ambivalent climate of opinions: tensions and dilemmas in understanding geoengineering experimentation Geoforum 80 82–92

Bellamy R, Chilvers J, Vaughan N E and Lenton T M 2013 ‘Opening up’ geoengineering appraisal: multi-criteria mapping of options for tackling climate change Glob. Environ. Change 23 926–37

Bellamy R and Lenza J 2015 Crafting a public for geoengineering Public Underst. Sci. 26 402–17

Bodansky D and Hunt H 2020 Arctic climate interventions Int. J. Mar. Coast. Law 35 596–617

Braun K and Könniger S 2018 From experiments to ecosystems? Reviewing public participation, scientific governance and the systemic turn Public Understanding of Science 27 674–89

Buck H J 2018 Perspectives on solar geoengineering from Finnish Lapland. Local insights on the global imaginary of Arctic geoengineering Geoforum 91 78–86

Burns W C G and Flegal J A 2015 Climate geoengineering and the role of public deliberation: a comment on the US National Academy of Sciences’ recommendations on public participation Clim. Law 5 252–94

Caldeira K and Wood I 2008 Global and Arctic climate engineering: numerical model studies Phil. Trans. R. Soc. A 366 4039–56

Callon M 1999 The role of lay people in the production and dissemination of scientific knowledge Sci. Technol. Soc. 4 1

Carr W and Yung L 2018 Perceptions of climate engineering in the South Pacific, Sub-Saharan Africa, and North American Arctic Clim. Change 147 119–32

Chilvers J and Kearnes M 2019 Remaking participation in science and democracy Sci. Technol. Human Values 45 1–34

Chilvers J and Kearnes M 2015 Science, democracy and emergent publics Remaking Participation: Science, Environment, and Emergent Publics ed J Chilvers and M Kearnes (London: Routledge)

Corner A, Pidgeon N and Parkhill K 2012 Perceptions of geoengineering: public attitudes, stakeholder perspectives, and the challenge of ‘upstream’ engagement WIREs Clim. Change 3 451–4

Corry O 2016 Globalising the Arctic climate geoengineering and the emerging global polity Governing Arctic Change: Global Perspectives ed K Kiel and S Knecht (London: Palgrave Macmillan)

Desch S J et al 2017 Arctic ice management Earth’s Future 5 107–27

Dove Z, Horton J and Ricke K 2021 The middle powers roar: exploring a minilateral solar geoengineering deployment scenario Futures 132 102816

Field L et al 2018 Increasing Arctic sea ice albedo using localized reversible geoengineering Earth’s Future 6 882–901

Finnish Meteorological Institute 2010 Lappi—ilmastonnuste [Lapland—climate projections]

Fiorino D 1990 Citizen participation and environmental risk: a survey of institutional mechanisms Sci. Technol. Human Values 15 236–57

Frumhoff P and Stephens J 2018 Towards legitimacy of the solar geoengineering research enterprise Phil. Trans. R. Soc. A 376 2119

Gregow H et al 2021 Ilmastonmuutoksen sepetuntojen ojauksen kiinto, kustannukset ja alueelliset ulottuvuudet Suomen ilmastopaneelin raportti 2/2021 (The Finnish Institute of Environmental Research: Helsinki)
Climate Change Panel) (available at: www.lmamostpanomefi.org/wp-content/uploads/2021/09/SUOMI-raportti_final.pdf) (https://doi.org/10.3390/ijerph18137064)

Gupta A and Moller I 2018 De facto governance: how authoritative assessments construct climate engineering as an object of governance Environ. Polit. 28 480–501

Hubert A-M 2021 A code of conduct for responsible geoengineering research Glob. Policy 12 82–96

IASSA 2020 IASSA principles and guidelines for conducting ethical research in the Arctic (available at: https://iassa.org/about-iassa/research-principles) (Accessed 18 October 2020)

IPCC 2019 Global warming of 1.5 °C (available at: www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Summary_Volume_Low_Res.pdf)

Jackson L S, Crook J A, Jarvis A, Leedal D, Ridgwell A, Vaughan N and Forster P M 2015 Assessing the controllability of Arctic sea ice extent by sulfate aerosol geoengineering Geophys. Res. Lett. 42 1223–31

Jiang J, Cao L, MacMartin D G, Simpson I R, Kravitz B, Cheng W, Visioni D, Tilmes S, Richter J H and Mills M J 2019 Stratospheric sulfate aerosol geoengineering could alter the high-latitude seasonal cycle Geophys. Res. Lett. 46 14153–63

Jones A C, Haywood M J, Dunstone N, Emanuel K, Hawcroft M K, Hodges K I and Jones A 2017 Impacts of hemispheric solar geoengineering on tropical cyclone frequency Nat. Commun. 8 1382.

Juhola S, Peltonen L and Niemi P 2012 The ability of Nordic countries to adapt to climate change: assessing adaptive capacity at the regional level Local Environ. 17 717–34

Knieling J and Othengrafen F 2009 Planning cultures in Europe between convergence and divergence: findings, explanations and perspectives Planning Cultures in Europe. Descending Cultural Phenomena in Urban and Regional Planning ed J Knieling and F Othengrafen (London: Ashgate) pp 301–21

Lee W, MacMartin D G, Visioni D and Kravitz B 2021 High-latitude stratospheric aerosol geoengineering can be more effective if injection is limited to spring Geophys. Res. Lett. 48 e2021GL092969

Lenton T M, Rockström J, Gaffney O, Rahmstorf S, Richardson K, Steffen W and Schellnhuber H J 2019 Climate tipping points—too risky to bet against Nature 575 592–5

MacCracken M C 2016 The rationale for accelerating regionally focused climate intervention research Earth’s Future 4 649–57

Macfarquhar G and Szerszynski B 2013 Living the future: an analysis of public discourse on solar radiation management and its implications for governance Glob. Environ. Change 23 465–74

McLaren D and Corry O 2021 The politics and governance of research into solar geoengineering WIREs Clim. Change 12 e707

Mettiäinen I 2013 Climate change in regional development strategies of an Arctic region, Case Finnish Lapland The Yearbook of Polar Law ed V G Alfredsson, T Koivurova and A Stepien (Leiden: Koninklijke Brill NV) pp 143–83

Miller C A and Wyborn C 2018 Co-production in global sustainability: histories and theories Environ. Sci. Policy 113 88–95

Moore J C et al 2014 Arctic sea ice and atmospheric circulation under the GeoMIP G1 scenario J. Geophys. Res. Atmos. 119 567–83

Moore J C, Gladstone R, Zwinger T and Wolovick M 2018 Geoengineer polar glaciers to slow sea level rise Nature 555 303–5

Moore J C, Mettiäinen I, Wolovick M, Zhao L, Gladstone R, Chen Y, Kirchner S and Koivurova T 2021 Targeted geoengineering: local interventions with global implications Glob. Policy 12 108–18

National Academies of Sciences, Engineering, and Medicine 2021 Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance (Washington, DC: The National Academies Press) (available at: http://map.edu/25762) (Accessed 26 March 2021)

Nature 2021 Give research into solar geoengineering a chance Nature 593 167

NSF (sa.) Principles for the conduct of research in the Arctic (available at: www.nsf.gov/geo/opp/arctic/conduct.jsp) (Accessed 2 November 2018)

Petrov A N, BurnSilver S, Chapin III F S, Fondahl G, Graybill J, Keil K, Nilsson A E, Riedlsperger R and Schweitzer P 2016 Arctic sustainability research: toward a new agenda Polar Geogr. 39 165–78

Pidgeon N, Parkhill K, Corner A and Vaughan N E 2013 Deliberating stratospheric aerosols for climate geoengineering and the SPICE project Nat. Clim. Change 3 451–7

Rasmus S, Wallen H, Turunen M, Landauer M, Tahkola J, Jokinen M and Laaksonen S 2021 Land-use and climate related drivers of change in the reindeer management system in Finland: geography of perceptions Appl. Geogr. 134 102301

Rayner S, Heyward C, Kruger T, Pidgeon N, Redgewell C and Savulescu J 2013 The Oxford principles Clim. Change 121 499–512

Regional Council of Lapland 2011 Lapin ilmastostrategia 2030 [Lapland’s climate strategy 2030] (in Finnish) (available at: www.lappi.fi/lapinliitto/c/document_library/get_file?folderId=2507452&name=DLFE-12330.pdf)

Shepherd J (The Royal Society) 2009 Geoengineering the Climate: Science, Governance and Uncertainty (London: The Royal Society)

Tilmis S et al 2018a CESM1(WACCM) stratospheric aerosol geoengineering large ensemble project Bull. Am. Meteorol. Soc. 99 2361–71

Tilmis S et al 2018b CESM1(WACCM) stratospheric aerosol geoengineering large ensemble (GLENS) project, National Center for Atmospheric Research (NCAR) [data set] (available at: https://doi.org/10.5065/D6HJXJXX)

Tilmis S, Jahn A, Kay J E, Holland M and Lamarque J-F 2014 Can regional climate engineering save the summer Arctic sea ice? Geophys. Res. Lett. 41 880–5

Turunen M T, Rasmus S, Bavay M, Ruosteenoja K and Heiskanen J 2016 Coping with difficult weather and snow conditions: reindeer herders’ views on climate change impacts and coping strategies Clim. Risk Manage. 11 15–36

Wibeck V, Hansson A and Anshelm J 2015 Questioning the technological fix to climate change—Lay sense-making of geoengineering in Sweden Energy Res. Soc. Sci. 7 23–30

Winickoff D E, Fegal J A and Asrat A 2015 Engaging the Global South on climate engineering research Nat. Clim. Change 5 627–34