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Engaging the Global South on climate engineering research

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The Global South is relatively under-represented in public deliberations about solar radiation management (SRM), a controversial climate engineering concept. This Perspective analyses the outputs of a deliberative exercise about SRM, which took place at the University of California-Berkeley and involved 45 mid-career environmental leaders, 39 of whom were from the Global South. This analysis identifies and discusses four themes from the Berkeley workshop that might inform research and governance in this arena: (1) the 'moral hazard' problem should be reframed to emphasize 'moral responsibility'; (2) climate models of SRM deployment may not be credible as primary inputs to policy because they cannot sufficiently address local concerns such as access to water; (3) small outdoor experiments require some form of international public accountability; and (4) inclusion of actors from the Global South will strengthen both SRM research and governance.

There is disagreement about whether and how to pursue climate engineering research, especially solar radiation management (SRM)[1]. The mere prospect of pursuing such research is an indictment of decades of failed efforts to reduce greenhouse gas emissions[2]. However, there is broad agreement that expanding debate with publics throughout the world is important for developing a credible way forward[3–7]. Calls for broader engagement on SRM are driven in part by the perception that a small group of elites, mostly scientists and policymakers from the USA and the UK, hold disproportionate power to define the research and policy agenda[8]. A related concern is that members of a 'geoclique' have vested stakes in initiating climate engineering research, and are unaccountable for the public's standing to gain or lose from the impacts of potential future SRM deployment[8,9].

Involving broader communities through public consultation and engagement has been one response to the perceived need to expand the circle of participation and accountability in climate engineering debates[3,10]. Long recognized as a tool for advancing democratic decision-making in technical arenas[11], public engagement exercises are participatory processes through which members of diverse publics express their views, concerns and recommendations about a techno-scientific issue[12–14]. Such efforts frame publics not as passive recipients of expert knowledge, but as important actors shaping technologies and their trajectories. Other means of involvement, albeit less deliberative, include interviews and surveys, which can register more perspectives and attitudes[10].

After reviewing the broader literature on public engagements in the SRM context, this Perspective analyses a recent engagement process with 45 mid-career environmental leaders, 39 of whom were from the Global South, in a workshop at the University of California-Berkeley (UC Berkeley). In particular, four key themes from this Berkeley workshop are identified and examined in detail: first, the 'moral hazard' problem should be reframed to emphasize 'moral responsibility'; second, climate models of SRM deployment are not always perceived as credible tools for producing knowledge about regional disparities in impacts; third, small outdoor experiments require some form of international public accountability, but not international regulation; and fourth, inclusion of actors from the Global South will strengthen both SRM research and governance. These themes are valuable contributions to ongoing discussions about SRM and might inform research and governance in this area.

Involving broader communities in debates

Owing to the controversial nature of the idea of climate engineering, policymakers and national research funders have made efforts to expand debates on climate engineering beyond circles of experts. As a more general matter, governments and academics have in recent years justified public engagement on emerging technologies in at least three ways. One line of argument is normative, holding that governance without meaningful public participation is inimical to democratic ideals[15,16]. Citizens, the argument goes, should have a powerful voice in determining whether and how a technology should affect their lives. A second justification is substantive. Non-experts will often identify issues, risks and solutions missed by experts. In addition, incorporating diverse perspectives will strengthen the relevance of knowledge produced and the utility of technologies and governance[17]. Finally, public participation may increase the perceived legitimacy of a technology and its governance, enhancing trust between scientists and lay publics. The rationale for engaging broader communities in the consideration of science policy is stronger only where the underlying issue may be politically contested and where scientific understandings remain underdeveloped or uncertain[18].

In the face of potential controversy, leading scientific and policy bodies have called for increased public engagement regarding SRM at national and international levels. The timing for processes of deliberation is good: the relative absence of entrenched interests at this early stage in the SRM concept enables a broader array of actors to meaningfully engage 'upstream'[10]. In response, researchers, scientists and government actors have increasingly pursued public engagement work over the past few years, and published accounts have accumulated. So far, some engagement efforts have been more deliberative than others, ranging from small workshops lasting a number of days to large public surveys[19]. Although productive discussions and processes have occurred elsewhere, this work has been heavily weighted towards the Global North, especially in the UK (see Table 1). In addition, deliberations in the Global South have been focused on building capacity among groups of stakeholders with previous knowledge and interest in climate change.

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Table 1 | Review of public engagements in climate engineering in the Global North.

Year	Title	Event	Location	Countries represented	Number of participants	Primary participant composition
2009	Royal Society	Focus groups	UK	UK	Unknown	General public
2010	Experiment Earth[20]	Deliberative workshops	UK	UK	85	General public
2010	US Government Accountability Office[54]	Survey	Online	US	1,006	General public
2010	Public understanding of SRM[25]	Survey	Online	UK, US, Canada	3,105	General public
2011	UK focus groups[23]	Focus groups	UK: Durham, Newcastle, London	UK	54	General public, but topic-specific variants
2011	Integrated Assessment of Geoengineering Proposals (IAGP) SPICE deliberative workshops[55]	Deliberative workshops	UK: Cardiff, Norwich, Nottingham	UK	32	General public
2012	IAGP public workshops[22]	Deliberative workshops	UK: Birmingham, Cardiff, Glasgow, Norwich	UK	44	General public
2012	Exploring early public responses to climate engineering[56]	Interviews (2009)	UK: southwest England, south Wales	UK	53	General public
		Survey (2010)	UK: England, Scotland, Wales	UK	1,822	General public
2014	Germany survey[57]	Survey	Online	Germany	1,040	General public
2014	Australia and New Zealand survey[24]	Survey	Online	Australia, New Zealand	2,028	General public

Global North. In the Global North, engagement exercises began in earnest in the wake of the 2009 Royal Society report *Geoengineering the Climate: Science, Governance and Uncertainty*[3]. The UK has featured prominently as a locus of planned public engagements on climate engineering. The dominance of the UK in this field is perhaps not that surprising given the 2009 report and the country's recent experiences with public engagement processes on genetically modified organisms and nanotechnology. Exercises in the UK have largely focused on the views of the general public (that is, non-experts). These deliberations were diverse in terms of the aim of the dialogue, framing of the issues, sampling methodology and substantive content, and generated nuanced insights into public views of climate engineering. A number of these dialogues were resourced by UK funding agencies, with some geared towards eliciting the general views of the lay public on future research into climate engineering (Experiment Earth)[20], and others aimed at understanding public views regarding particular proposed experiments (SPICE)[21]. More recent efforts, drawing on lessons learned from earlier deliberations, sought to avoid particular framings of climate engineering as 'natural' or as an emergency response to climate change, and to reduce the dominance of experts in shaping deliberation[22,23]. Efforts to understand public views of climate engineering have also occurred, to a lesser extent, in Australia, Canada, Germany, New Zealand and the USA, but in the form of surveys, not deliberations. Broadly speaking, these efforts have focused on the extent to which the general public approves or disapproves of research into climate engineering, and findings have been split. In Australia and New Zealand, researchers found that "overall public evaluation of climate engineering is negative"[24]. In a survey of publics in Canada, the UK and the USA, researchers concluded that "there was strong support for allowing the study of SRM"[25].

Beyond the Global North. There have been few concerted efforts to expand the public debate outwards beyond the Global North (see Table 2). The most visible is the Solar Radiation Management Governance Initiative (SRMGI) organized jointly by the Royal Society, the Environmental Defense Fund and the World Academy of Sciences. Launched in March 2010, SRMGI has aimed to "build a diverse community of well-informed international stakeholders, and to encourage international cooperation and transparency over SRM research governance"[26].

SRMGI began at the Kavli Royal Society International Centre in the UK, where an international group of scientists, social scientists, policymakers and public intellectuals gathered to discuss whether and under what circumstances SRM research should begin[27]. Although it was international in nature, the Kavli event drew a large majority from the Global North and developed countries. While the Kavli process produced a set of findings regarding the importance of developing governance for SRM, the need to involve different kinds of actors, especially from the Global South, emerged as a central theme[27]. As a consequence, SRMGI was continued largely as a set of discussions and public engagements outside the Global North.

Small events throughout the world have ensued under the aegis of SRMGI, which structured meetings using a set of lectures, exercises, moderated discussions and breakouts. Events in Senegal, South Africa and Ethiopia in 2012 and 2013 revealed a wide range of opinions concerning, for example, the governance of research and deployment, mechanics of governance, public engagement, education and research in Africa, and the next steps for African engagement with SRM research governance[26]. In general, participants—largely comprising scientists, students and government officials from Africa with high scientific literacy—tended to cautiously support research, with different views about the kinds of research that should be permitted to proceed, over what time period and under what conditions. There was great interest in further engagement in SRM in Africa and the idea of a 'staged approach' to research, intended to prevent a rush to deployment. With respect to African engagement, participants strongly supported 'capacity-building' in the area of SRM governance, with an emphasis on the importance of international cooperation both inside and outside Africa.

SRMGI is not alone in organizing engagements. In August 2013, the Institute for Advanced Sustainability Studies and the Pacific Centre for Environment and Sustainable Development at the University of the South Pacific co-convened an open-discussion workshop about climate engineering in Suva, Fiji[28]. The workshop consisted of 30 participants from 12 Pacific island countries and territories, and was intended to facilitate the exchange of information, perspectives and ideas about climate engineering. Participants were largely experts in climate change and SRM issues, including scientists, engineers, students, government officials and

Table 2 | Review of deliberative workshops in climate engineering beyond the Global North.

Year	Title	Location	Countries represented	Number of participants	Primary participant composition
2011	SRMGI Kavli conference[27]	Kavli, England	UK, Italy, Bangladesh, Kenya, Canada, China, USA, Ethiopia, Netherlands, Austria, Switzerland, Uganda, Sweden, Pakistan, Brazil	46	Academia, civil society and government with some prior exposure to SRM science and/or policy
2011	SRMGI, S. Rajaratnam School of International Studies Centre for Non-Traditional Security Studies, Oxford Climate Engineering Programme[58]	Singapore	Philippines, Singapore, Japan, UK, India, USA	38	Academia, civil society and government with some exposure to climate change science and policy, and some prior knowledge of SRM science and/or policy
2012	SRMGI, African Academy of Sciences, The World Academy of Sciences[26]	Senegal	21 African nations (including Cameroun, Ethiopia, Ghana, Kenya, Nigeria, Senegal, South Africa), Austria, USA, UK, Canada	47	Academia, civil society and government with varied exposure to SRM science and/or policy
2012	SRMGI, African Academy of Sciences, The World Academy of Sciences[26]	South Africa	21 African nations (including Cameroun, Ethiopia, Ghana, Kenya, Nigeria, Senegal, South Africa), Austria, USA, UK, Canada	18	Academia, civil society and government with varied exposure to SRM science and/or policy
2013	SRMGI, African Academy of Sciences, The World Academy of Sciences[26]	Ethiopia	21 African nations (including Cameroun, Ethiopia, Ghana, Kenya, Nigeria, Senegal, South Africa), Austria, USA, UK, Canada	43	Academia, civil society and government with varied exposure to SRM science and/or policy
2014	Institute for Advanced Sustainability Studies[28]	Fiji	Germany, Fiji, Cook Islands, Tonga, Nauru, Vanuatu, Tokelau, Kiribati, Solomon Islands, Samoa, Tuvalu, USA	30	Academia, civil society and government with varied exposure to SRM science and/or policy
2014	Governance of solar geo-engineering research: African perspectives and engagement	Tanzania	Ethiopia, Ghana, Namibia, Nigeria, Rwanda, South Africa, Sudan, Tanzania, Germany, Italy	21	Academia, civil society and government with varied exposure to SRM science and/or policy

non-profit representatives. Participants in this workshop agreed to key messages that echoed themes emerging from SRMGI, but put greater emphasis on the need for enforceable governance structures before field testing or deployment of climate engineering technologies, a finding consistent with norms emanating from the Global North, for example, the Oxford Principles[5]. The group also decided that it would be advantageous for the Pacific region to develop a common stance on climate engineering to ensure regional input into the international debate and decision-making.

As is evident from the examples discussed above, which have included scientists and civil society leaders from the developing world, calling these 'public engagements' may be misleading insofar as 'public' connotes the involvement of 'lay' or a 'general public'. It is worth noting, as a general matter, that the field of public engagement suffers from conceptual imprecision in its binary distinction between technical experts and the public, and many of the engagements described above are case in point. There is no necessary equivalency between scientists and 'experts', or non-scientists and 'lay public'. First, there are different forms of expertise, so a sharp dichotomy between 'expert' and 'public' fails to capture nuances in the status of participants and different forms of expertise in operation[29,30]. Second, expertise is context dependent and can be based on experience rather than training[31,32]. A hydrologist or wildlife ecologist, for instance, may have less relevant knowledge about SRM than a member of civil society without formal scientific training but who has taken a great interest in the issue. Likewise, social scientists can operate as credible experts in technical debates about regulation and the intersection of science and governance. This is important as we look at the participants in the SRM public engagements in the Global South to date, and indeed at the Berkeley workshop, where participants have not been experts in SRM technical sciences, but have in fact possessed knowledge and experience relevant for SRM deliberations.

The Berkeley workshop

Motivated by the strong need to continue to expand and diversify the communities deliberating this issue, a team at the UC Berkeley, in partnership with SRMGI and UC Berkeley Beahrs Environmental Leadership Program (Beahrs ELP), conducted a two-day workshop on SRM research governance from 12 to 22 July 2014. The Berkeley workshop was embedded in the Beahrs ELP, a three-week programme for certification in sustainable environmental management. The programme involved 45 mid-career environmental leaders in the field of sustainable development from 30 countries, 87% of whom were from the developing world (see Table 3). Note that very few participants had expertise in SRM, but many possessed technical knowledge and experience in relevant disciplines and professions, for example, environmental management, law and the sciences, working across government, private and non-governmental organization (NGO) sectors. Locating the workshop within this larger certificate programme offered advantages in terms of geographical, professional and gender representation (see Figs 1 and 2). Participants had already been working together in an educational context, which created a level of social comfort that enabled frank discussion. Further, because they were mostly mid-career environmental leaders, pre-existing knowledge about climate issues was generally high, which provided a good platform for discussion. This also means, as discussed below, that the groups should not be taken as representative of a 'general public' from the Global South.

Methods. The Berkeley workshop consisted of presentations from faculty and researchers on the science and governance aspects of the topic, plenary dialogue, small group discussions and panel discussions. A small set of readings about climate engineering had been circulated prior to the workshop, carefully chosen to represent a range of opinions on the need for research. The meeting was guided by the principle that, subsequent to early presentations, participants

Table 3 | UC Berkeley workshop: geographical representation and participant backgrounds.

Countries represented	
Africa	Djibouti, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mozambique, Nigeria, Senegal, South Africa, Tunisia, Uganda
Americas	Brazil, Chile, Ecuador, Mexico, Peru, USA
Asia	Afghanistan, Bangladesh, China, Japan, Laos, Mongolia, Myanmar, Pakistan, Nepal, Philippines, Singapore, Sri Lanka, Timor-Leste, Vietnam
Australia	
Europe	Denmark, England, Switzerland
Participant backgrounds	
Agricultural economics	
Agricultural engineering	
Agronomy and agroecology	
Environmental law	
Geosciences	
Environmental impact assessment	
Natural resources management	
Water resources management	
Fisheries management	
Marine ecology	
Forestry	
Wildlife conservation	
Land rights and access	
Climate change and community adaptation	
Poverty, gender and livelihoods social policy	
Rural development	
Ecotourism and sustainable development	
Sustainable business	
Urban planning	
Waste management	
Environmental education	
Media and community development	
Employers	
Universities	
UN agencies	
World Bank	
Development banks	
Government agricultural institutes	
Government research institutes	
Government ministries	
Military engineering institutes	
Wildlife conservation societies	
Biodiversity conservation societies	
World Wildlife Fund	
Environmental NGOs	
Development NGOs	
Public health NGOs	
Community-based NGOs	
Private environment consulting firms	
Industrial firms	

should collectively decide on which topics required the most discussion within panels and breakout groups. Day 1 concluded with a panel discussion entitled 'Where does climate engineering fit within the larger politics of climate change?' Day 2 involved a review of some of the themes that emerged on the first day of the workshop and featured a talk by A. Asrat (a coauthor of this Perspective) on impacts of climate change in Africa, and African perspectives on SRM research and governance. Day 2 closed with a plenary discussion on possible mechanisms for institutionalizing broader participation in SRM research and governance, and a short online survey of opinions and attitudes about climate engineering research governance developed by the Berkeley team.

Like previous SRMGI meetings, the Berkeley workshop used specific scenario exercises in which participants deliberated on hypothetical outdoor SRM experiments: the first, a small one-time release of harmless smoke from a sea vessel to test its effects on cloud albedo (that is, cloud brightening); the second, a larger-scale sulphate particle injection by a small number of aeroplanes big enough to test potentially adverse impacts of an SRM deployment on stratospheric ozone (about 500 tons over several months). These experiments were loosely based on studies of a hypothetical nature discussed at a recent conference by leading climate engineering researchers[33] and were used to explore intuitions about the processes and principles of research oversight and governance.

To characterize and analyse the debate, detailed notes were taken in all sessions of the workshop, including each small breakout group. Participants filled out index cards to provide comments and thoughts, and these were collected and collated. All notes were then qualitatively analysed using a process of open line-by-line coding[34]. These codes were then used to organize the data in a table, and broader concepts were identified based on these codes to capture larger-scale themes and relationships among codes. Survey data were tabulated and used to validate themes that emerged from the coding process.

There are pitfalls in trying to apply methods of deliberation that are developed in the Global North to communities in the Global South, where there are sharply different political concerns and cultures of expertise[35]. However, we note that an African scientist was one of a small number of lecturers, and workshop participants led or co-led breakout groups themselves and reported findings back to the group as a whole. The event was embedded in a social environment already conditioned by open-ended exchange and mutual learning. And the organizing group made efforts to generate open-ended deliberative exercises, in which all views were to be welcomed and respected.

Discussion. The Berkeley workshop provides a potentially important window into the opinions and concerns among a particular class of educated and rising leaders in sustainable development in the Global South. The Global South is far too big and complex — geographically and otherwise — to say that the group was representative: indeed, there was selection bias towards those with a strong interest in sustainable development. Nevertheless, participants were representative in the sense that they frequently referenced the people of their regions, expressed regional concerns and assumed roles of regional experts.

Although there is no simple way to characterize the range of opinions at the Berkeley workshop, certain ideas emerged clearly. First was the overarching message that the Global South should be part of the decision-making process for climate engineering, because the issue of climate change is of global concern and implicates everyone. This strong finding echoes previous SRMGI events[24]. Second, there was a wide range of opinions expressed about the meanings and value of SRM research. Although there were many concerns expressed about SRM research, some participants felt there was actually a compelling obligation to explore the concept of climate engineering. Third, there was a set of four strong themes that emerged that should be taken seriously by policymakers and scientists, because they shed important light on existing debates and framings. These themes require deeper description and analysis.

From 'moral hazard' to 'moral responsibility'. One dominant frame asserted in the argument about climate engineering is the idea of 'moral hazard', that is, that climate engineering research and development might undermine motivation to pursue climate mitigation and adaptation, particularly in the developed world[3,36–38]. Owing to its perceived importance to the governance debate, this hypothesis has received a great deal of attention in the social science literature and has been tested in public engagements and surveys in the Global North with conflicting findings[39].

At the Berkeley workshop, moral hazard was less of a concern than 'moral responsibility', that is, that climate engineering research might deflect the burden of the Global North for its role in the climate problem. Would the possibility of climate engineering tacitly or explicitly undermine the claims that the North was in moral debt for polluting the sky? There was a strong sense that, especially in the context of global climate talks, discussions of climate engineering are a way for rich countries to deflect attention and erase a history of disproportionate energy consumption, by dangling the prospect of a cheaper, easier and faster alternative. As one participant put it, climate engineering can "be seen as another process of getting away from the responsibility, and that's why some people are saying, 'No. Climate change mitigation and adaptation should remain the top priority'." Accordingly, the conduct of research in SRM was seen as an intervention in the ongoing ethical debate about proper remedies for climate change.

Despite the fact that the discussions around climate engineering at the Berkeley workshop were framed by climate politics writ large, the participants did consider ways in which climate engineering experimentation might be desirable and even morally required. One key idea was that rules on experimentation in climate engineering might be linked to binding rules on climate mitigation and adaptation. For example, some participants suggested that certain climate engineering experiments should move forward only when particular mitigation and adaptation obligations had been met. But a number of participants felt that climate engineering should not be a way for the Global North to circumvent power sharing in the climate negotiation process.

The credibility of models. So far, climate modelling constitutes the bulk of climate engineering research[40]. What can these modelling studies tell us about whether there might be regional winners and losers in a climate-engineered world? This question lies at the heart of much of the international discussion about the utility of climate models as an evidentiary base for climate engineering policy[41,42]. Some have argued that model-based evidence suggests global SRM will "further destabilize regional climates"[41], or that "climate engineering can't please everyone"[42] and "solar climate engineering in short is a zero-sum game: some will win, some will lose"[41]. Those individuals hold that models are currently too uncertain to be useful in considering the impacts of climate engineering[41]. In contrast, other scientists hold that there is "no scientific paper that backs this [the claim that there will be increased regional instability] up"[41] and that, in fact, model evidence so far suggests that moderate amounts of solar climate engineering will benefit everyone[43].

At the Berkeley workshop, participants entered directly into these debates about the sufficiency of using climate models as a foundation for SRM research governance. There was agreement that climate models might be one tool, among others, for understanding climate engineering. However, there was concern that modelling constitutes the primary evidence driving SRM research and policy at this stage, and risks closing down debates about regional inequities.

First, there was concern about the resolution of global climate models and their inability to address the potential impacts on scales of concern. Participants persistently wanted to know what climate engineering might mean to local communities in their regions, both in terms of physical impacts of deployment and involvement in governance. Are results sufficient if they address the 100 km by 100 km grid level, or is the relevant scale still smaller? The absence of assurances in models that localities (individual farms, towns and regions) would be made better off called into question the sufficiency of these tools as a sound basis to say that climate engineering would not pose serious risks to people in their countries. Second, some participants who were in the scientific community raised the issue of the validation of global climate models. In some cases, these models are validated against palaeoclimatic and historical data; data that are, for many reasons, largely unavailable in the developing world. As a result,

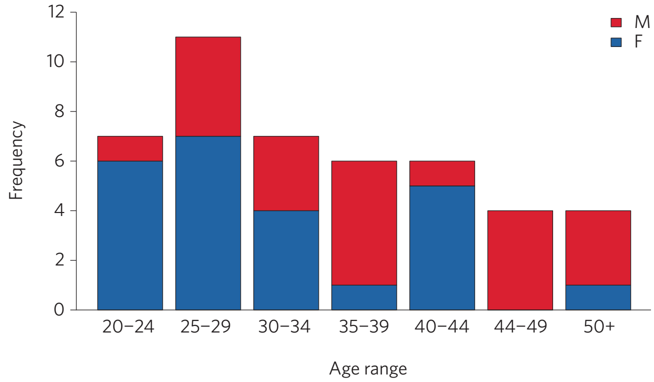

Figure 1 | Age and gender distribution of participants at the Berkeley workshop.

models are often tuned to results from North America and Europe, which generated some discomfort among workshop participants. Third, some participants were very concerned about the accuracy of models to predict impacts on precipitation, a limitation acknowledged in the scientific literature[44]. Many communities in the Global South largely survive on rain-fed subsistence agriculture, making this a life-or-death issue. Together, these concerns reflected a general concern about scientists' level of confidence in the technical basis for promoting experimentation.

Governance of small experiments. Under what circumstances outdoor research experiments should be allowed to proceed without additional regulation is a leading question in climate engineering governance debates. Some analysts have suggested the need to define an allowed zone of research, based on likely physical impact, under which experiments would be permitted to proceed with only minimal new regulatory requirements[45]. Some have advocated particular thresholds expressed in units of physical forcing[46]. In this zone, experiments would be deemed to be of such small physical risk that formal oversight, beyond that required for typical outdoor experiments, would be disproportionate and unnecessary.

At the Berkeley workshop, the themes of accountable and credible oversight, even for small experiments, were centrally important. When participants were presented with the model cloud brightening experiment discussed above, they nearly all thought that such an experiment should be left to the oversight and discretion of local jurisdictions. However, a number of participants wanted to probe the identity and interests of those providing oversight, suggesting the importance of credibility of local experts among international publics. They expressed concerns that experimentation currently lacked transparency and that future work needed to be more visible to civil society. They also expressed the view that, although there should not be international regulation, there should be lines of accountability for oversight institutions at a higher level, which would be positioned to come into play should experiments meet a certain threshold of global concern or trigger international law.

For many participants, the need for some form of accountability at higher levels of governance grew out of concerns that went beyond the immediate physical risk of experiments, a finding consistent with previous research on public engagement[23]. Owing to the possibility of a slippery slope from small experiments to further research and possible deployment, the publics potentially affected by small experiments are not just local ones. For the participants, potential slippage to larger experiments and deployment, with implications for physical risk as well as power asymmetries across the Global North and South, elevated concern about small experiments. This supports the idea that there is a scalar mismatch between the physical scope of small experiments and their potential social impact:

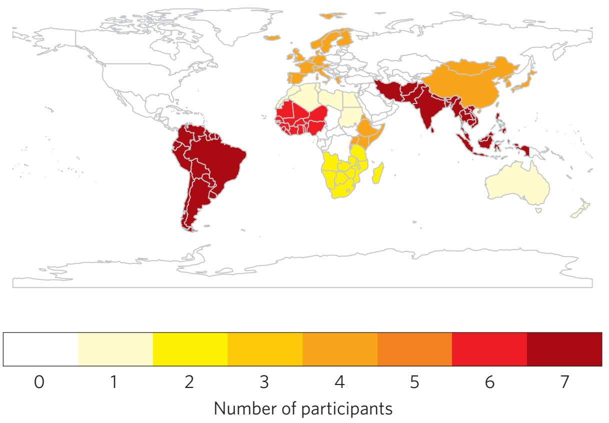

Figure 2 | Geographic distribution of participants at the Berkeley workshop. Colours reflect the number of Berkeley workshop participants from each of the 23 United Nations Global Environment Outlook sub-regions. For country-specific information regarding participants, see Table 3.

even minimal-risk outdoor climate engineering experiments may be of concern to broader publics, both in the USA and abroad.

The rationales of scientific cooperation and inclusion. In previous engagements and discussions, a clear theme has emerged that 'capacity building' among scientific and civil society communities in the developing world will be critical if discussions are to be more inclusive[26]. Inclusivity on the policy and governance side has been assumed to be the goal. The Berkeley workshop confirmed that participants agree about the capacity points, but these points forcefully emerged in the conduct of the workshop itself.

On day two of the meeting, one of our African organizers — A. Asrat, a geoscientist working on Quaternary climate history and climate change — a geoscientist working on Quaternary climate history and climate change, presented to the group. The presentation focused on the perspective of Africa as a location facing distinct climate change challenges, some in common with other tropical areas, particularly those surrounding precipitation. Prior to that, it had been a mix of modellers, international lawyers and academics from the Global North presenting background on the issue to foment deliberative discussion. According to our focus groups and questionnaire after the event, this presentation was particularly important. Until this presentation, many participants had been concerned about whether they were being told the whole story about climate engineering. Some stated that they began to appreciate the potential importance of climate engineering only when it was contextualized by someone from the Global South. This presenter filled a credibility gap by virtue of speaking as an African scientist addressing the unique concerns of the tropics. The fact that he was also able to point out some of the shortcomings in how the relevant scientific case for climate engineering research (and climate research more generally) has been composed, especially in terms of regional data biases, also made him a trusted figure on day two of the event.

These experiences suggest that if climate engineering is to enter a new phase of research, the community of experts itself must strive for greater geographical representation. The reasons are threefold. First, broader inclusion in designing models and experiments for climate engineering (and climate change in general) could help promote the closure, for instance, of data gaps in many geographical areas, which currently impair the validity of prediction. It may also make science more relevant to global publics by directing scientific attention to issues of greatest concern, for example, impacts on precipitation. Second, there are very real perceptions of potential power asymmetries in research and development, and joint knowledge production might help foster political cooperation. As one participant put it, "We talk about having this plan B, but who is going to be designing this plan B?" Broader participation could begin to address real and perceived geopolitical imbalances entailed in the conduct of climate engineering research. In this regard, broader inclusion and exchange, and the greater information sharing and transparency it might engender across the Global North and South, were seen as a potential path to producing a shared knowledge base among broader publics[47]. There is ample evidence from the social studies of science that the credibility of scientific knowledge, especially that used to justify controversial policy, will depend on the broad acceptance of the procedures of its making[48–50]. Finally, given constrained resources in the Global South, the small number of scientists from the Global South involved in climate science and the unequal contribution of the Global North to climate change, some participants felt that the developed world should commit resources to training and involving more climate scientists from the Global South.

Conclusion: institutionalizing inclusion

Climate engineering policy must be seen as inseparable from the larger policy landscape of climate change, and must therefore include the scientific, moral and political dynamics of greatest concern to the developing world. The Berkeley workshop was one attempt to further the goal of bringing more diverse perspectives into the debate on SRM. Perhaps as expected, the broader politics of climate change were seldom absent. Far from disabling the discussion, however, the integration of climate politics with climate engineering discussions produced a set of thematic concerns that offer real insight as research and governance in SRM begins to unfold. Furthermore, insofar as these themes are responsive to the political and moral context of the climate change arena, they may be more robust and useful touchstones as SRM discussions inevitably gain more exposure and encounter political realities.

It is also impressive to see how the themes at the Berkeley workshop illustrate the interpenetration of scientific and social issues in the SRM field. This is remarkable insofar as the consideration of values and techniques are often bifurcated, to the detriment of both, in science and technology policy[51,52]. Demonstrating the potential power of upstream engagement, the findings of the workshop — especially regarding models and scientific expertise — support the need to pursue discussions of the science and governance of climate engineering in the same breath.

The themes discussed above also show, ironically, how discussion alone will not promote meaningful engagement of the Global South. Rather, informed by discussions like these and many others, policymakers and relevant communities must turn towards the important work of institutionalizing inclusion within research and governance as they unfold. A set of ideas for institutionalizing inclusion follows.

First, some well-respected policymakers believe that climate engineering governance might bypass the intense politics that have characterized the Kyoto process by advancing research and research governance through a club of industrialized countries[53]. If the Berkeley workshop is one indication, Global South actors may view such an approach as an abdication of moral responsibility, further undermining larger efforts on climate change. Owing to real and perceived slippery slopes, even small outdoor experiments must be accountable to publics beyond the immediate jurisdiction of the experiment. An international body with significant representation from the Global South, perhaps within an existing institution such as the World Meteorological Organization, will probably be needed to produce accountability in climate engineering science and governance. But for small experiments, the need for accountability might be satisfied through transparency and reporting requirements, rather than direct oversight.

Second, the production of science and governance that are credible on a global level will probably require the inclusion of

Global South actors in four activities that combine technical and value-based dimensions: defining the most relevant climate engineering problems; designing models and experiments that best study them; collecting climate data where there are current gaps; and facilitating the exchange between experts and the broader society. These activities will require the development of networks of scientists and civil society actors within and across countries of the Global South, and strong efforts by scientific and political institutions of the Global North to engage and integrate those networks.

Institutionalizing inclusion in these ways requires investments in energy, time and money to build the necessary capacity. Luckily there are now models for doing so. A new pan-African working group on SRM research and governance issues was established in a meeting held in Tanzania on 14 August 2014 (convened by A. Asrat) under the auspices of the 25th Colloquium of African Geology. Composed of climate and environmental researchers from Africa, members of the Young Earth Scientists network from Africa and representative of the African Academy of Sciences, this working group will network among interested African stakeholders and serve as a focal point for African discussions on SRM. It aims to consolidate more opinions from various stakeholders, identify research agendas and facilitate cooperation among African and international players. Ultimately, the group seeks to grow an African centre of research on SRM governance through an African university with the help of the African Academy of Sciences. The working group has started building on its membership base and coordinating the individual efforts and initiatives of various researchers in Africa. Moving forward, such efforts to institutionalize expertise and create region-specific resources will be critical for deepening the role of the Global South in policymaking in international forums.

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