Designing Procedural Mechanisms for the Governance of Solar Radiation Management Field Experiments: Workshop Report

CIGI

DESIGNING PROCEDURAL MECHANISMS FOR THE GOVERNANCE OF SOLAR RADIATION MANAGEMENT FIELD EXPERIMENTS

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WORKSHOP REPORT

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February 23-24, 2015
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Cover: The Peace Tower, West Block and Library of Parliament from the west grounds of Parliament Hill, Ottawa. iStock photo.

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ABOUT THE AUTHORS

Jason J. Blackstock is the head of department and senior lecturer in science and global affairs at University College London's Department of Science, Technology, Engineering and Public Policy and an adjunct associate professor at the University of Waterloo's School of Environment, Enterprise and Development. With a unique background spanning research physics, technology development, public policy and international affairs, he is a leading international scholar and policy adviser on the interface between science and global public policy. Prior to joining University College London, Jason led international research and policy engagement programs on climate change, energy and geoengineering from both the International Institute for Applied Systems Analysis (Austria) and CIGI.

Neil Craik is the director and an associate professor of law in the School of Environment, Enterprise and Development at the University of Waterloo, where he teaches and researches in the fields of Canadian and international environmental law. His current research examines the role of procedural obligations in governance structures addressing transboundary and global commons environmental issues.

Jack Doughty is a researcher in climate engineering governance in the Department of Science, Technology, Engineering and Public Policy at University College London. Previously, he was at the UCL Office of the Vice Provost of Research. Jack completed a master's degree in public policy at King's College London in 2012.

Joshua Horton is a postdoctoral research fellow at the Belfer Center for Science and International Affairs at the Harvard Kennedy School, where he conducts research on geoengineering policy and governance issues. Before joining the Belfer Center, Josh worked as an energy consultant for a global consulting firm. He holds a Ph.D. in political science from Johns Hopkins University.

ACRONYMS

EIA	environmental impact assessment
IRB	institutional review board
MCB	marine cloud brightening
MOCX	Mesoscale Ocean Cloud Experiment
MSGX	Mesoscale Stratospheric Geoengineering Experiment
NAS	National Academy of Sciences
SIA	social impact assessment
SRM	solar radiation management
SEA	strategic environmental assessment
SAI	stratospheric aerosol injection
SCoPEx	Stratospheric Controlled Perturbation Experiment

EXECUTIVE SUMMARY

This two-day workshop brought together 17 policy officials, physical scientists and governance scholars, predominantly from the United States and Canada, to consider and evaluate governance mechanisms that may be useful for managing proposed solar radiation management (SRM) field experiments.

Two specific procedural mechanisms were under consideration: environmental impact assessments (EIAs) and research registries. To ensure discussions were as realistic as possible, participants used a set of recently published SRM field experiment proposals as hypothetical examples when considering and evaluating both mechanisms.

The workshop operated under the Chatham House Rule,[1] and no attempts were made to forge consensus positions or to generate policy recommendations. Rather, this workshop was exploratory in nature, with discussions ranging widely along with personal opinions on some topics. Despite this variety however, five broad conclusions emerged from the workshop:

1. The scale of any individual experimental proposal notably shapes the main governance challenges raised, with larger experiments posing different challenges compared to smaller experiments. As each governance mechanism is more or less effective for different challenges, there is unlikely to be a single mechanism that will be effective across all scales.

2. EIAs are well suited to deal with local environmental impacts, but generally poorly equipped to manage deliberative processes surrounding broad political and policy questions. Consequently, EIAs are most relevant for larger-scale SRM experiments, although new climate or atmospheric impact measures would likely need to be developed. For small-scale experiments, where immediate environmental impacts are essentially negligible, the utility of EIAs is limited to providing trusted third-party verification of the local risks.

3. Transparency mechanisms such as research registries, if well designed, may contribute to building societal trust around SRM research. However, such mechanisms cannot replace the political processes necessary to engage the public in discussions about SRM research within the broader context of climate change management.

4. Any individual experimental proposal could, if considered on its own, end up creating a public or policy debate that in effect becomes a referendum on all SRM field research. Presenting experiments within the context of an SRM field research program — including thresholds where publicly supported political decisions would be necessary before further stages would proceed — may alleviate some aspects of this challenge, although it highlights the question of where SRM fits within the broader portfolio of climate research.

5. The social, ethical and political questions that accompany proposed experiments, particularly larger-scale experiments, cannot be satisfactorily addressed using EIAs and registries alone. Deliberative, participatory and programmatic mechanisms designed to consider fundamental political and policy issues, as well as to build trust among societal actors, must be considered and explored.

The unexpected ocean fertilization experiment off the west coast of Canada in 2012 highlights the reality that non-governmental actors can already initiate small- to medium-scale environmental experiments, without government funding or approval. This is equally true for SRM field experiments. Without careful consideration and development of a governance framework for SRM experimentation, governments could be caught out having to respond ad hoc to situations driven by non-governmental actors.

INTRODUCTION

From February 23-24, 2015, a two-day workshop was held in Ottawa in order to consider specific governance tools that may be used in connection with SRM field research activities. The goal of the workshop was to provide a concrete set of process-oriented mechanism options for evaluation by a range of Canadian and US government officials who are likely to soon be faced with SRM field experiment proposals. The two procedural mechanisms that were the focus of the workshop were EIAs and research registries. A number of recently published SRM field experiment proposals were also presented to the workshop participants to guide and support their evaluation of the potential governance mechanisms. The workshop attendees (17 in total), included scientific experts with interests in conducting SRM field experiments and government officials drawn from environmental regulation, research funding and science policy areas, as well as social scientists with expertise in climate engineering governance.[2]

1 The conference was conducted under the Chatham House Rule. Under this protocol, those present, including media, "are free to use information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed." For a full explanation of the Chatham House Rule, see www.chathamhouse.org/about-us/chathamhouserule.

2 A number of civil society groups were invited to participate, but were unable to attend for logistical reasons.

BACKGROUND AND MOTIVATION

SRM, as an emerging field of science and technology with global implications, raises complex governance demands. To date, much of this governance discussion has been conducted at a high level of abstraction with policy makers, natural and social scientists and non-governmental actors seeking to develop high-level principles to govern research activities, but with less focus on the precise design of the mechanisms that may be used to assess and oversee these activities. Two existing mechanisms, EIAs and research registries, have been identified in past assessments of SRM technologies as having particular salience in promoting scientifically sound, transparent and consultative governance of research (Rayner et al. 2013; Royal Society 2009; National Academy of Sciences [NAS] 2015). While these two mechanisms are well understood in their current applications, SRM research governance is likely to raise new issues and complications that deserve attention. The aim of this workshop was: to explore the possible application of these mechanisms to SRM research activities in greater depth; to engage both experimentalists and members of the policy community in considering the potential design parameters for these mechanisms; and to assess the ability of these mechanisms to satisfy governance demands. The geographic focus of the workshop was North America.

This workshop is part of a larger research program on procedural mechanisms to address climate engineering governance that is supported by research funding from the Social Sciences and Humanities Research Council of Canada and the Centre for International Governance Innovation. As described below, the workshop drew on the work that arose out of a previous workshop held in March 2014 at Harvard University, which brought together SRM experimentalists to develop a "credible and broadly representative set of field experiment proposals" in relation to SRM (Keith, Duran and MacMartin 2014). The workshop also drew on a similarly-themed workshop held in Potsdam, Germany, in April 2014 (Moore, Schafer and Lawrence 2015).

WORKSHOP STRUCTURE

The workshop was organized around a portfolio of hypothesized SRM field experiments. These experiments focus on two particular SRM approaches, stratospheric aerosol injection (SAI) and marine cloud brightening (MCB). In order to capture a full range of experimental possibilities, the experiments considered in the workshop included outdoor tests of enabling technology (but involving no perturbations), micro-scale process experiments, scaling tests occurring at larger geographic scales and climate response tests, which would seek to produce a detectable climate signal.

The workshop participants were asked to engage in three principal tasks. First, they were asked to identify the range of potential concerns to which each of the experiments may give rise. The participants were then asked to separately consider the extent to which EIAs and research registries could address the concerns and the kinds of procedural reforms that might enable the mechanisms to more effectively address the concerns. These three tasks were carried out in breakout groups, with different groups focusing on different sets of experiments. Each group was asked to examine at least one experiment in each of the "process study" and "scaling test" classifications (see below for further detail). In addition, each group was asked to consider whether different considerations arose in connection with either a "technology development experiment" at one end of the perturbative spectrum or a "climate response test" at the other.

The breakout sessions were preceded by presentations providing background information on the experiments and on each of the mechanisms to ensure all of the participants were proceeding from a common understanding of the subject matter. These sessions were followed by a plenary discussion in which breakout group findings were relayed to the entire group and discussed.

A final plenary was held to consider other possible mechanisms or approaches that would address research governance concerns. No attempts were made to forge consensus positions or to generate policy recommendations; instead, the approach was more exploratory in nature. The results discussed in this report should therefore not be understood as representing a consensus or majority view; rather, the intent is to describe the substance of the points raised and the ensuing discussions.

PROPOSED EXPERIMENTS

In order to ground the discussion in a more concrete set of proposals, the workshop structured its discussion around a set of SAI and MCB experiments described in Keith, Duran and MacMartin (2014). These experiments were chosen because they represent the type and form of field experiments that are likely to be proposed to funders and regulators. Ideally, these experiments would operate in an iterative and sequential manner, with subsequent phases informed by the scientific outcomes of earlier phases. The typology of experiments, which relates to both SAI and MCB, consists of the following phases:

- Technology development — focused on hardware development and operations (no chemical processes);
- Process study — a micro-scale analysis of physical, chemical and radiative processes (not going beyond the scale of natural perturbations);
- Scaling test — intended to validate models and assess how processes may vary across scales (conducted at the mesoscale level — 1 to 1,000 km^2); and

- Climate response test — designed to elicit a large-scale climate response.

The scientific backgrounds of SAI and MCB are described elsewhere (NAS 2015; Caldeira, Bala and Cao 2013). For present purposes, both technologies rely on enhancing the albedo effect of light-scattering particles (in the case of SAI) or of whiter clouds (in the case of MCB) to reduce the amount of radiative energy that stays within the earth's atmosphere, which in turn would have a cooling effect. While the basic mechanisms underlying the technologies are understood, there remain outstanding questions with respect to the potential impacts of the perturbations and the impacts on temperature and precipitation at larger scales. It is anticipated that experimentation would provide further knowledge on these issues, which would inform modelling activities.

POTENTIAL CONCERNS

The participants were divided into three breakout groups to discuss the proposals and identify key concerns associated with the different stages. Each group was asked to focus on different sets of experiments.[3] The groups focused on the process study and scaling stages of the proposals. In addition, all groups were asked to consider the technology development and the climate response test as framing experiments, representing opposite ends of the field experiment spectrum. Here, the intention was to have the breakout groups turn their attention to SRM-related experiments that did not involve perturbation, but did advance SRM technology development, as well as how impact considerations may change at much larger (regional or global) scales with clear climate response implications.

The issues identified were as follows:

- There were no appreciable degrees of differentiation between the SAI and MCB experiments at the process study and scaling levels. (As a consequence, we do not describe the impacts by breakout group or technology, except where there were differences.)
- Despite the minimal predicted environmental impacts of the process study experiments, all groups remained concerned that there may be local environmental impacts or other physical risks, including unintended consequences. While these concerns merited investigation, the more prominent risks, particularly at the process study scale, were not physical in nature.
- At small scales, but increasingly at larger scales, there were potential concerns regarding the ability to distinguish impacts attributable to experimental activity from natural variability.
- At larger scales, i.e., larger-scaling tests, there would be concern over transboundary impacts.
- There was a set of concerns that related to intellectual property and ownership of technologies that led to broader concerns over the control of technologies as they developed.
- There were concerns related to the potential for technological lock-in.
- The impact that experimentation may have on broader discussions and political action regarding mitigation and adaptation is often framed as a moral hazard concern, but also as a broader political risk, in the sense that the public may view government funding or approval of SRM experimentation as signalling a lower commitment to other climate action.
- At larger scales, the political risks also entailed geopolitical (North-South) dimensions.
- The broader political, social and ethical issues were more of a concern at experimental stages beyond process studies, i.e., scaling tests and climate response tests.
- Approval or funding may give rise to a set of cost/benefit concerns, including the risks/costs of non-action.
- Technology development decisions that facilitated SRM experimentation raised the same political and social concerns.
- The risks from climate response tests were difficult to assess, given the more abstract nature of the experiments proposed and the uncertain governance apparatus that would need to be developed to address the much broader scale of impact.

EIAs

Following a presentation that outlined the EIA process and the ways it has been adapted and applied to different areas, the workshop participants examined how the process would apply to SRM field experiments.

EIAs entail the scientific assessment of proposed projects using a process grounded in engagement with public and other agencies and in consultation with multiple stakeholders. Full EIA processes are triggered when authorities determine that a proposed activity is likely to cause significant, non-negligible environmental impacts. Public authorities often must consider inputs from this process when deciding whether to allow projects to proceed, but EIA does not typically require risk avoidance or mitigation as a substantive obligation.

3 With reference to the portfolio of experiments identified in Keith, Duran and MacMartin (2014), the breakout groups focused on the following experiments: Breakout Group 1 — Stratospheric Controlled Perturbation Experiment (SCoPEx), Mesoscale Stratospheric Geoengineering Experiment (MSGX); Breakout Group 2 — MCB 1–3, Mesoscale Ocean Cloud Experiment (MOCX); Breakout Group 3 — MCB 1–3, MSGX.

EIA serves many functions including the identification and evaluation of risk; planning; disclosure of information; democratic accountability; and promotion of norms. EIA is both incremental and contextual. Similar forms of assessment have been designed to address broader issues, such as strategic environmental assessment (SEA) and social impact assessment (SIA). EIA is not, however, closely linked to technology assessment.

Language under domestic EIA legislation (the US National Environmental Policy Act and the Canadian Environmental Assessment Act) may allow for the application of EIA to SRM field trials. The use of EIA to evaluate SRM experiments is widely viewed as appropriate, since it has previously been applied to similar research on other emerging technologies. EIA has been elaborated by the London Convention/London Protocol to help ensure the legitimacy of future ocean fertilization experiments (London Protocol 2013).

The EIA process typically follows a prescribed format requiring government officials and proponents to participate in assessment and engagement activities across a number of distinct stages.

- *Screening* — It is necessary as a preliminary matter to determine whether an activity is subject to an EIA. There will be rules regarding the basic coverage of the EIA requirement; for example restricting the application of the EIA system to only physical projects (excluding government plans or programs) that are subject to some form of government control. Once the basic application is determined, the near universal threshold requirement is that the activity must have some potential to cause significant harm to the environment.

- *Scoping* — Where it is determined that an activity will be subject to an EIA, the scope and terms of the EIA study are determined, in many cases, through consultation.

- *Impact Assessment* — The study itself is prepared, most often under the direction of the project proponent, and is submitted to an overseeing agency. The study requirements often obligate the proponent to consider both the direct and cumulative impacts of the project, the alternatives to the project and the impacts of those alternatives.

- *Public Consultation* — The study is subject to both public and agency consultation, which requires publication of the study and opportunities for comment. The extent of these opportunities varies considerably, even within a single system, ranging from notice and comment processes to administrative hearings.

- *Final Decision* — The report and the results of the public consultation process are submitted to the final decision maker, most often the government agency overseeing the activity. The decision maker is obligated to consider the results of the EIA, but in the event that significant environmental impacts have been identified, the decision maker is not required to avoid or mitigate the extent of those effects.

- *Follow-up* — Where a project is undertaken, there is often a further requirement for post-project monitoring and the adoption of adaptive management practices to address any unforeseen environmental impacts.

Breakout Group Evaluations of EIA

Keeping with their assigned breakout groups and experiments, the groups were asked to apply the EIA process to their experiments, looking specifically at how each of the stages described above could be utilized to address the previously identified issues.

The top-line result that emerged from the discussion was that EIA was a necessary but insufficient procedural tool to address concerns associated with SRM field experiments. All three breakout groups generally agreed that EIAs, while capable of addressing some of the governance challenges posed by SRM field experiments, would be unlikely to provide effective governance mechanisms covering all aspects of the proposed experiments. It was felt that EIAs would be particularly ineffective at the technology development and process study levels, because any environmental impacts arising from such small-scale experiments would likely be negligible and therefore fail to trigger full EIA processes; as such, there would be limited opportunities for public engagement. However, EIAs were considered to be an important part of experimentation at the scaling test level because a significant impact on the environment would be more likely.

The screening stage was approached differently by the groups, particularly in regard to the process study experiments. One breakout group felt that EIAs would be inapplicable to the process study experiments as the physical impacts would have minimal environmental impacts and would fall below the required threshold for an EIA. Another group raised the idea that EIAs could potentially be carried out for process studies based on whether the proposed experiment was a “feasibility” test (i.e., should experiments that are likely to be scaled up be subject to EIA requirements). This feasibility would depend on whether the technologies involved in the proposed experiment could be easily scaled up to enable moderate- to large-scale deployment. A further point raised was that policy makers should not assume a governmental action trigger, given both the potential for private funders to support experimentation and uncertainty regarding other regulatory triggers, such as permits for releases into air or water. On the latter point, the application of pollution control legislation to experimental proposals was identified as an important area for future clarification.

The groups mostly agreed that the scope of EIAs should be confined to environmental impacts. Social and ethical questions, viewed as primarily applicable to scaling and climate response tests, were considered less amenable to assessment under an EIA framework.

The groups viewed the role of public participation within an EIA framework differently. While one group saw it as playing an important part in any experiment, another felt the public only needed to be informed at the larger-scale experimentation stage.

Overall, the groups viewed EIAs as only partially capable of addressing the multitude of issues raised in the first breakout group. While they agreed that EIAs played an important role in the scaling and climate impact tests, the less significant environmental impacts involved in the smaller-scale experiments meant that their role for technology development and process studies was much more focused on ensuring that any localized impacts were minimal. Furthermore, while EIAs would likely be more useful in evaluating the environmental risks posed by larger-scale experiments, they could not encompass the broad assessment of pertinent social and ethical issues.

Two alternative institutional mechanisms were put forward in this conversation. First, an institutional review board (IRB) might be charged with deliberating on whether proposed experiments had adequate scientific merit and should be pursued. Second, SEAs carried out at the program (such as a research funding program) level might explore relevant social and ethical issues before experiments were carried out. Because SEAs are designed to be broader and more comprehensive than project-level EIAs, such programmatic assessments may be better suited to addressing many of the social and political issues that would likely confront larger-scale field tests.

RESEARCH REGISTRIES

The second day of the workshop began with a presentation on different types of research registries and other transparency mechanisms utilized in different scientific fields. Workshop participants, again in breakout groups, discussed how a hypothetical registry might address the issues identified on the first day.

In the context of potential SRM field research, transparency is generally regarded as playing an important role both in building social trust and in minimizing environmental risk. Calls for transparency in geoengineering research governance have come from a variety of sources, including the NAS Report, the Royal Society Report and the Oxford Principles, among others (NAS 2015; Royal Society 2009; Rayner et al. 2013; for a general discussion, see Craik and Moore 2014). While there are many calls for transparency to play a central role in SRM field research, what a transparency mechanism for SRM research would actually look like is unclear. A registry could vary along multiple dimensions, including public versus private research, voluntary versus mandatory compliance and national versus international scope.

The participants were presented with a range of possible options and examples that might apply to SRM research. This included case studies on nuclear power, radioactive waste, nanotechnology, clinical trials and genetically modified organisms. Institutional variations among these examples offer different possible paths for SRM governance. Two key options include a multi-stakeholder collaborative system designed to inform decision makers and a clearing house or registry mechanism that would present information about research plans, environmental risks, results, etc. Alternatively, the status quo might prove adequate if current regulations and processes, such as research funding disclosure requirements, were determined to provide adequate detail to stakeholders.

Breakout Group Evaluations of Research Registries

The breakout groups were asked to discuss the potential of a research registry for addressing the governance concerns they had identified in the first session. Since research registries exhibit a greater variety of institutional forms than EIAs, the groups were asked first to identify key characteristics of a research registry mechanism that could address the transparency demands associated with SRM field experimentation and then to discuss any shortcomings that might be evident. Key registry design variables included:

- purpose (what would be the main objective of the registry?)
- trigger (which experiments would be included?)
- audience
- information
- timing
- compliance (mandatory or voluntary?)
- ownership (the mechanism could be operated by an international organization, such as a treaty body, a UN agency, a consortium of national research regulators or by a non-governmental organization); and
- evaluation.

The breakout groups unanimously agreed that the primary function of any research registry for SRM field trials would be to facilitate public trust in the research and to help create a social license to conduct experiments. However, a registry mechanism was viewed as incapable of addressing most of the governance concerns that had been raised. All three groups designed a registry that would primarily inform the public. A registry was not seen as particularly valuable for scientists, who were regarded by the groups as operating within a community in which they would already have access to relevant information through existing structures and publications.

There was disagreement on exactly what an effective and useful registry would look like. While one group saw a registry as only applicable to outdoor research that was explicitly intended to help develop SRM, another thought that perhaps a wider net should be cast to cover indoor research such as modelling.

Views on the types of information to be included, and the timing of submission, differed from group to group. Two groups envisioned a registry that would require researchers to supply scientific and technical details of their experiments, perhaps tied to regulatory requirements. However, this proposed arrangement raised concerns that scientists might have lower incentives to update the registry with results if there were no regulatory trigger to require continued disclosure. One group felt that information should be high level only, with basic descriptions intended for a lay audience.

The groups disagreed on the extent to which a potential registry should be mandatory or not. Only one group designed a registry model that was not voluntary, with others arguing that it would be too difficult to police and therefore inadvisable. The groups expressed a variety of views on the questions of ownership and evaluation, without reaching clear conclusions on either.

While all three groups discussed the need for public trust in SRM experimentation and thought that a research registry could contribute to gaining this trust, they argued that a research registry would not be enough in and of itself to achieve this goal. On top of this, the participants all thought that a registry would not address the myriad other environmental and social concerns that had been raised in the first discussion.

FINAL DISCUSSION

Following the session on research registries, a final plenary discussed overarching issues and tentative conclusions reached over the course of the workshop. Two principal themes emerged in this discussion.

First, participants expressed difficulty with evaluating individual SRM field experiment proposals without seeing how each experiment fit into a larger program of SRM research. This quickly raised broader questions about how such a program of SRM research would fit within the broader landscape of climate mitigation and adaptation research. The complexity of this broader question, and the likelihood of considerable political discussion and debate to ensue around this question, was noted by numerous participants.

Most participants nonetheless expressed a desire to see some SRM outdoor research proceed. There were no major objections to the type of process study experiments currently advocated as the next stage in research. However, there was concern that without a politically agreed program of SRM research, any decision made on a single experiment could, in effect, turn that experiment into a political referendum on all further SRM research. Some participants suggested that such a "referendum point" might be approaching regardless of any progress on research governance, and participants highlighted the urgency and importance of ensuring that policy makers be as informed and as prepared as possible.

These political concerns also tied closely to the second principal theme of discussion, namely, that participants unanimously identified the need for a greater level of public engagement. It was widely agreed that the governance mechanisms discussed in the workshop would likely be insufficient to engage the public as fully and comprehensively as necessary to ensure effective governance of SRM field trials. Participants argued that scientists would need to take part in some degree of public consultation and outreach and that numerous ways of facilitating public participation in the governance process exist.

With regard to communicating with the public, attendees noted the importance of highlighting that the salient issue is governance of research, not advocating deployment. Workshop participants from government agencies and environmental organizations felt that a greater understanding of the public's likely reaction to SRM technologies and research would assist decision makers in their pursuit of public policy goals.

Participants suggested that useful outputs from the workshop might include policy briefings written in plain language and aimed at policy and media audiences. Attendees also favoured the idea of a follow-up meeting looking at other potential mechanisms; in particular, participatory technology assessment and additional public engagement processes used previously for controversial environmental issues (such as nuclear waste management).

CONCLUSIONS

Five key conclusions emerged from the workshop.

First, the salience of individual issues and concerns regarding proposed SRM field experiments may vary based primarily on the type of experiment under consideration. Process studies, for example, are likely to entail negligible environmental risks, but may trigger intellectual property concerns relating to core technology development. Conversely, scaling tests may pose more significant environmental risks but raise fewer intellectual property issues, since such tests involve scaling up existing technologies. Because different governance mechanisms address different governance challenges, the applicability of mechanisms to different types of experiments is likely to vary.

Second, with regard to EIAs, because EIAs are designed principally to assess risks posed by significant environment impacts, this mechanism may be much more applicable to larger-scale experiments, such as scaling tests and climate response tests, than to smaller-scale experiments, such as process studies and technology development trials. Indeed, as the latter are likely to produce negligible environmental impacts, EIAs, without further regulatory intervention, may be inapplicable to small-scale tests. Furthermore, as a mechanism intended primarily to evaluate environmental rather than social or ethical impacts, and equipped with limited deliberative capabilities, EIAs are ill suited to consider the broader political and policy questions that are likely to accompany larger-scale field tests. Despite these shortcomings, EIAs would provide a useful forum for discussion of physical and related risks and trusted third-party validation of low-level risks.

Third, in the context of SRM field experiments, the primary function of research registries and other transparency mechanisms is likely to be trust building among the public rather than risk minimization. Conventional resources such as academic networks and peer-reviewed journals may be adequate to provide researchers and other interested parties with sufficient information regarding experimental protocols and results. Such resources will be unlikely, however, to effectively communicate scientific findings to the public at large and even less likely to engender public trust in SRM science. Transparency mechanisms such as research registries, if well designed, may contribute to building societal trust. However, they cannot replace the political processes that will be necessary to effectively engage the public in discussions about SRM research in the broader context of climate change management.

Fourth, evaluating individual SRM field experiment proposals on a case-by-case basis presents some challenges. While dealing with early-stage experiments individually enables a focus on the specific, and frequently negligible, environmental risks, there is no appropriate governance mechanism for engaging broader societal concerns about the future implications of SRM research at this scale. As a result, any individual experiment could become a public referendum on SRM research, played out via public media and even local or regional government. Defining a program of SRM research, comprised of a series of proposed experiments, and including clear opportunities for broader public engagement before various experimental thresholds are crossed, could provide an alternative way forward. However, articulating such a program raises the question of how SRM research fits within the broader portfolio of climate research, which poses another set of political challenges.

Finally, the preceding points make clear that effective governance of SRM field research will require mechanisms beyond EIAs and research registries. The social, ethical and political questions that will accompany proposed experiments, particularly larger-scale experiments such as scaling and climate response tests, cannot be satisfactorily addressed using EIAs and registries alone. Instead, deliberative, participatory and programmatic mechanisms designed to consider fundamental political and policy issues, as well as to build trust among societal actors, must be either adapted from existing institutions or created from scratch. Possible starting points include an SEA, an SIA, technology assessment, responsible innovation processes and stakeholder engagement processes such as public commissions.

APPENDIX 1:

DETAILS OF PROPOSED SRM EXPERIMENTS CONSIDERED

Proposed MCB Experiments

The MCB field experiments would entail injecting ~80 nm salt particles into marine stratocumulus clouds for the purpose of creating greater cloud cover. Scientists cannot create clouds in a laboratory; therefore, a need exists to conduct outdoor MCB field trials. Field experiments would investigate five key sets of processes: creation and injection of particles; dispersion of particles; microphysical responses of clouds; dynamical responses of clouds; and macrophysical responses of clouds. (For further background, see Wood and Ackerman 2013; Russell et al. 2013.)

One group of proposed MCB experiments would take place in three sequential phases:

- MCB 1 (technology development) — This experiment is to test whether appropriate sized particles can be generated and lifted into the planetary boundary layer. Thus one experimental stage tests the spray technology.

- MCB 2 (process study) — A second experimental stage would involve spraying a small amount of particles over land for two weeks in order to investigate cloud condensation nuclei and drop dispersion in a single track and the microphysical response. Delivery would be land-based, but adjacent to the marine environment. Small aircraft sampling would be employed. For MCB 1-2 combined, estimated total timeline from project initiation to closure is two years. To be regarded as successful, MCB 1-2 would need to cause a detectable microphysical change.

- MCB 3 (process study, scaling test) — This experiment would be conducted on a ship at sea, away from land to minimize outside influences. MCB 3 would entail a single ship plume, possibly with multiple sprayers, and was proposed to create a smaller perturbation than those from existing ship tracks. Sampling by ship and two or three aircraft would permit observations from above, below and inside the cloud. The experiment would require four weeks to complete. Estimated total timeline from project initiation to closure is two years. To be regarded as successful, MCB 3 would need to cause a detectable climate signal.

- MOCX (scaling test, mesoscale) — The other proposed MCB experiment is MOCX, a technology development and scaling test involving multiple plume generation and sampling by aircraft and ship. The experiment would require four weeks to complete. Estimated total timeline from project initiation to closure is two years. To be regarded as a success, MOCX would need to cause a detectable mesoscale climate signal.

Each proposed MCB experiment was described as having a smaller impact on the environment than existing ship tracks, and no detectable changes to local climates or ecosystems would be expected.

Proposed SAI Experiments

The proposed SAI experiment would involve the release of aerosols in the stratosphere in order to assess the microphysical dynamics of the release and at large scales to assess the radiative forcing impacts of such releases. As with the MCB experiments, outdoor experimentation is required with SAI, due to the complexity of the interactions observed.

The first proposal is SCoPEx, a process study designed to measure possible ozone loss in artificially perturbed stratospheric air, which is a potential impact of critical importance to assessing the viability of SAI technologies (Dykema et al. 2014). The SCoPEx experiment has two stages. First, to conduct these tests, SCoPEx investigators would develop a propelled balloon to create and monitor a region of perturbed chemistry in the stratosphere. The technology development stage would be directed toward assessing the design of the delivery system, but would not involve any release. The focus of the experiment is a process study that would test models of chlorine activation in high-H_2O mid-latitude conditions using <1 kg of sulphur and <100 kg H_2O. In addition, SCoPEx would test models of stratospheric mixing, as well as test the ability to generate and observe regions with perturbed aerosols and chemical constituents. Any environmental effects would be expected to be reversed within a year.

The second proposed SAI experiment is MSGX. The MSGX experiment would entail sustained stratospheric injection of H_2SO_4 from an aircraft. The effects of this technology development and scaling test would be large enough to detect with remote sensing instruments. Injected particles would have a one- to two-year life cycle.

In addition, participants were asked to consider either technology development or climate response tests. In both cases, an SAI experiment was considered.

- For the technology development experiment, participants were asked to look at the Stratospheric Particle Injection for Climate Engineering II experiment, which would involve carrying out the previously cancelled technology development test of flying a tethered balloon to a height of one kilometre and injecting a few tens of kilograms of water vapour into the atmosphere. The purpose of this test would be to demonstrate the feasibility and advance engineering knowledge of this system for possible future use in aerosol injection, but the test itself would involve only water (i.e., no chemically active species).

- For the climate response test, few details are provided. In short, it would involve SAI conducted at sufficiently large scales and durations to allow for the measuring and assessment of targeted climate response parameters, such as ground or sea-surface temperature.

WORKSHOP PARTICIPANTS

Jason Blackstock (University College London)

Neil Craik (University of Waterloo)

Jack Doughty (University College London)

Joshua Horton (Harvard Kennedy School of Government)

David Keith (Harvard Kennedy School of Government)

Tom Ackerman (University of Washington)

Albert Lin (University of California, Davis)

David Estrin (CIGI)

Nigel Moore (Institute for Advanced Sustainability Studies, Potsdam)

Ralph Bodle (Ecologic Institute, Berlin)

Dane Berry (Council of Canadian Academies)

Marc Saner (University of Ottawa)

Andy Miller (US Environmental Protection Agency)

Government of Canada officials

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The Centre for International Governance Innovation is an independent, non-partisan think tank on international governance. Led by experienced practitioners and distinguished academics, CIGI supports research, forms networks, advances policy debate and generates ideas for multilateral governance improvements. Conducting an active agenda of research, events and publications, CIGI's interdisciplinary work includes collaboration with policy, business and academic communities around the world.

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Le CIGI a été fondé en 2001 par Jim Balsillie, qui était alors co-chef de la direction de Research In Motion (BlackBerry). Il collabore avec de nombreux partenaires stratégiques et exprime sa reconnaissance du soutien reçu de ceux-ci, notamment de l'appui reçu du gouvernement du Canada et de celui du gouvernement de l'Ontario.

For more information, please visit www.cigionline.org.

CIGI MASTHEAD

CIGI

67 Erb Street West
Waterloo, Ontario N2L 6C2, Canada
tel +1 519 885 2444 fax +1 519 885 5450
www.cigionline.org