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Geoengineering in the Canadian Arctic: Governance Challenges

Jill Barclay
NAADSN Post-Graduate Fellow

Purpose: To explore the impacts of the potential deployment of Solar Radiation Management (SRM), a form of geoengineering, in the Canadian Arctic.

Although geoengineering technologies are potential remedial measures to mitigate and slow climate change, there remains no governance framework that can be applied to address the impacts and costs of such projects. This policy primer examines the potential use and governance of Solar Radiation Management (SRM) to increase albedo (reflectivity) in Canada's Arctic region and divert incoming solar radiation to slow the warming of Arctic sea ice and permafrost.

This primer considers governance models that may be applied to SRM governance in Canada. It is designed to help inform policymakers and other stakeholders of important considerations when contemplating frameworks. Given the serious threats that climate change poses to human security, Canada needs to be prepared for the proposed use of geoengineering to address these increasingly pressing issues.

The Critical Importance of the Arctic

The warming of the climate is being experienced worldwide; however, the rate of climate change in the Arctic is significantly higher than that of the rest of the globe. According to the Fifth Assessment Report (A5) of the Intergovernmental Panel on Climate Change (IPCC), the warming of the Arctic's ocean and atmosphere is unequivocal and Arctic sea ice is vanishing at an increasingly accelerated pace.[1] The strongest warming is found in the northern high-latitude regions, which includes the Canadian Arctic. It is estimated that the summer Arctic could be ice-free as early as the 2030s.[2]

Because Arctic sea ice is crucial to balancing global climate systems, the loss of ice cover would dramatically and severely increase the positive feedback loop in the climate system, further contributing to the warming climate. Sunlight that would otherwise be reflected by sea ice would instead be absorbed. Moreover, the carbon dioxide (CO_2) that is already circulating through the Earth's climate system will remain for millennia to come.[3] Further exacerbating the warming climate is the release of methane gas into the atmosphere as sea ice continues to melt. Methane, chemically known as CH_4, is trapped within permafrost and the Arctic seabed.

Similar to CO_2, its release into the atmosphere would substantially aggravate climate change, not only in the Arctic, but globally.[4]

As Arctic sea ice continues to decrease drastically and climate mitigation strategies continue to fall short, there is a greater appeal to implementing climate-altering technologies, or geoengineering, to slow climate change. Geoengineering solutions, which alter the Earth's processes in order to slow or halt climate change, come in many forms, ranging from altering the acidity of the ocean to creating artificial cloud cover. All forms, however, are controversial because they are often extremely large and intense undertakings and their effects could, and likely would, extend beyond their immediate geographic borders.[5] This policy primer recognizes the growing interest in geoengineering methods and examines how these technologies, specifically Solar Radiation Management (SRM), could be governed in a way that would align with national laws and regulations, as well as international environmental treaties, if introduced in the Canadian Arctic.

Arctic Climate Change is Accelerating

Arctic amplification has created a positive feedback loop unique to the Arctic region. As the temperature of the Earth's surface continues to rise, Arctic ice melts at increasing rates. Arctic sea ice and snow cover are vital to keeping the Arctic cool by reflecting the sun's solar radiation, thus maintaining a stable global climate. Multi-year Arctic sea ice, which is correspondingly multi-layer, limits the amount of solar radiation absorbed due to its high albedo (reflectivity). However, as sea ice melts, less solar radiation is being reflected, increasing the absorption of solar radiation at the surface, thus melting more sea ice and contributing to the positive feedback loop.[6] Preventative environmental measures aimed at protecting sea ice could slow the powerful climate feedback loop. Even minor slowing of this feedback loop would make global climate change easier to manage and address moving forward, making geoengineering an appealing option to achieve such a result.[7]

The Potential of Geoengineering

There is a vast number of remedial, mitigation, and restoration strategies and technologies that fall under the broad category of geoengineering. Within this broad category, there are two general methods of geoengineering technologies into which these strategies fall: carbon dioxide reduction (CDR) and Solar Radiation Management (SRM). At the most general level, CDR aims to remove and sequester greenhouse gases, while SRM reduces the amount of solar radiation being absorbed by the Earth. These projects all vary in scale, cost, and effectiveness.

I. Carbon Dioxide Reduction

CDR often focuses on the removal of CO_2 (as opposed to other greenhouse gases) due to its longer lifetime, abundance in the atmosphere, and relatively slower response to mitigation efforts.[8] Because greenhouse gases are the primary cause of Earth's rising temperatures (primarily CO_2), removing them would, in principle, decrease the Earth's temperature, mitigating further damage caused by climate change.[9] There are a number of forms of CDR, ranging from traditional land-based techniques like afforestation, reforestation, and avoided deforestation[10] to more technically advanced methods including carbon dioxide capture from ambient air, through which the air captured is processed in a way that retains the CO_2.[11] CDR methods differ in scale, environmental impacts (both positive and negative), and cost. CDR is relatively slow and therefore is intended for use in conjunction with climate change mitigation efforts. Moreover, significant research is required before any CDR technology is deployed on a commercial scale.[12]

II. Solar Radiation Management

Solar Radiation Management (SRM) aims to alter the Earth's albedo, or reflectivity. Ice caps and bright surfaces, like Arctic sea ice, reflect incoming solar radiation naturally. Radiation that is not reflected gets absorbed, warming the surface of the Earth.[13] The Arctic's accelerated rate of warming is due to polar amplification feedbacks. Fresh snow has the capability to reflect up to 90 percent of incoming sunlight, while sea ice reflects up to 70 percent. In contrast, open water absorbs most sunlight, only reflecting about 6 percent. As ice and snow melt, this creates more open water that absorbs more sunlight, therefore feeding into the positive feedback loop of Arctic amplification.[14] SRM is not a solution addressing the root cause of climate change, but rather a temporary response to climate change by increasing the amount of sunlight that is reflected.[15]

There are a number of SRM technologies that take place on distinctive levels including atmospheric, terrestrial, and space-based. One of the most common SRM techniques is stratospheric aerosol injection. Stratospheric aerosol injection aims to increase albedo by mimicking a natural volcanic eruption. Volcanic eruptions dramatically increase albedo as they inject small volumes of reflective aerosols into the atmosphere, reflecting some of the incoming solar radiation and cooling the Earth's temperatures.[16] Stratospheric aerosol injections are like an artificial volcanic eruption, whereby sulfide aerosols are injected into the stratosphere to reflect incoming sunlight.[17] However, it is estimated that stratospheric aerosol injections, while being the most rapid and cost-effective method of SRM, would also require ongoing deployment. Stopping the technology once in use could have the opposite effect of its intended goal, inducing a rapid "rebound warming," whereby temperatures increase at an exaggerated pace over a short period of time when the built-up greenhouse gases are no longer masked from the atmosphere.[18]

Geoengineering in the Arctic Context

Recently, the Arctic has been identified as needing locally-focused efforts to slow, stop, or mitigate the extreme effects of global temperature rise in the region.[19] Strategies that have previously been proposed by academics and environmental scientists include using wind-powered pumps to pump Arctic sea water onto winter ice with the intention of thickening the ice over the winter seasons, brightening sea water around Arctic ice with hydrosols, and other Arctic ice restoration efforts using ocean surface albedo modification.[20] Techniques aside, it is clear that the Arctic has already been identified as a location for geoengineering deployment to combat the effects of Arctic amplification.

At present, most forms of CDR remain exceedingly expensive with average costs to sequester and store atmospheric carbon coming in at US$100 per ton of carbon removed. To contextualize this, humans produce 20 billion tons of CO_2 per year.[21] Sequestering even a quarter of the amount produced each year would cost $500 billion annually. Effective CDR mechanisms are still being developed and the funding and logistics for extracting 20 billion tons of CO_2 per year are beyond the current realm of capabilities for most countries or institutions.[22] Even the more cost-efficient CDR methods like afforestation and land management are nonviable options for the Arctic's extreme and harsh climate.

However, there currently exist a number of SRM methods that are being deployed at a fraction of the cost of CDR. For example, the annual cost of delivering enough sulfuric particles into the stratosphere via stratospheric aerosol injection to combat greenhouse gas warming is estimated at US$2-8 billion, depending on the method of deployment.[23] While still costly, it is clearly a much cheaper option. To put these costs in perspective, the damage caused by our current rate of emissions is roughly US$200 to $2,000 billion per year.[24] Cheaper still is the SRM technique of Surface Albedo Modification (SAM) that is estimated to cost US$1 to $5 billion yearly if deployed in areas of 100,000 square kilometres.[25]

Surface Albedo Modification

Given that CDR remains too costly to be used even regionally, and that both atmospheric Solar Radiation Management technologies outlined above would require global implementation to effectively influence the climate, it is unlikely that these geoengineering techniques will be deployed in the very near future.[26] The risks of large-scale geoengineering techniques are significant and mostly unknown, as most deployment has been theoretical. For this reason and for its cost-effectiveness, this policy primer focuses on the regional Arctic application of SRM technologies.

The terrestrial-based method of Surface Albedo Modification (SAM) is an Arctic-specific SRM technology that targets terrestrial areas of land or sea ice to increase their albedo. One form of this technique uses reflective microspheres of silica (glass) to increase the albedo of young, thin ice, mimicking snow cover.[27] Thin ice is the target of SAM efforts because of its low albedo. Covering it in reflective materials protects it from melting under the increased summer temperatures, preventing more ice loss and promoting ice gain in winter months. Over time, the ice may be conserved and converted into more reflective multi-layer, multi-year ice. As ice is restored, more solar radiation will be reflected, therefore reducing the rate at which Arctic, and global, temperatures increase.[28] While SAM is being deployed in small-scale experimental trials with promising results, its end goal is to be strategically deployed in a large, but localized, area. Current small-scale deployments of SAM on frozen lake test sites in Utqiagvik, Alaska, Lake Elmo, Minnesota, and at the University of Manitoba's Sea Ice Environmental Research Facilities (SERF) in Winnipeg, among other locations,[29] have shown a low-risk, localized, and potentially reversible solution to restoring sea ice by increasing the reflectivity of thin ice.

Without intervention, sea ice in the Arctic will continue to decrease, further diminishing the albedo in the Arctic and increasing global climate temperatures. More and more people see geoengineering as a necessity more than an option, making it a matter of *when* rather than *if.*

The Social and Ethical Implications of Geoengineering

I. Intentional Manipulation of the Earth's Climate

Perhaps the most basic ethical question asked about geoengineering is whether or not it is moral to even attempt to alter the Earth's climate. While it could be said that humans have already altered the climate so drastically that we are the reason climate-altering technologies are being considered at all, it is the mere intent of altering the climate that makes geoengineering an act distinct from our unintended impacts on the environment in previous years.[30] While some argue that the fact humans have caused climate change is reason enough not to make any efforts to alter the climate further, advocates of geoengineering point out that even non-geoengineering projects aimed at climate change mitigation are effectively interfering with the Earth's climate system.[31] The risks of doing nothing to mitigate or slow climate change are far greater than the risks associated with limiting warming and other mitigation efforts.[32] In the Arctic specifically, a climate warming of 0.5˚C is the difference between an ice-free Arctic in a decade's time versus a century's. That is, if we can limit climate warming to 1.5˚C instead of 2.0˚C, we can effectively reduce the loss of the Arctic sea ice that is so imperative to the Earth's climate system.[33]

Regardless of differing views on geoengineering, the social and cultural lens through which geoengineering is examined affects how it is perceived. Some consider geoengineering a technological fix to a fundamentally social problem. This makes geoengineering incompatible with those who believe climate change must be addressed through economic, social, and political transformations.[34] However, if climate change continues at the rate it is now, we may not have the time needed to undergo those transformations that would address the causes of climate change at its core.[35] One aspect of the geoengineering debate on which ethicists have reached a consensus is that climate-altering technologies cannot and should not be used as the sole remedy for such a complex problem. Mitigation efforts must come first. Moreover, if geoengineering is to be used at all, it should be done in conjunction with mitigation efforts.[36]

II. Vulnerable Populations and Uneven Outcomes

If geoengineering were to take place on a global scale, there are questions of who would be consulted to make the decisions of deployment and who would be effectively in charge of altering the climate. It is well documented that people who live in low-income countries are disproportionately negatively impacted by climate change while also contributing to climate change the least.[37] Similarly, it is unlikely that the citizens in these countries would have the resources or representation to properly take part in the decision-making processes of geoengineering deployment.[38] Further, climate modelling research has suggested that deploying a geoengineering technology like stratospheric aerosol injection in the Northern Hemisphere may trigger droughts in the Southern Hemisphere.[39] As a result, the adverse effects of geoengineering could, much like climate change, be most detrimental to vulnerable communities in low-income countries. This is perhaps the most pressing ethical and moral issue debated by ethicists evaluating geoengineering. Populations with the least capacity to adapt to climate change and little power at the international level will similarly be the populations most vulnerable to any negative consequences of geoengineering.[40]

The impacts of geoengineering raise challenging ethical questions. Questions asked include: would some countries benefit while others suffer negative impacts? Would those experiencing negative impacts have avenues to seek redress or compensation for these negative impacts?[41] Ultimately, the question is: who will benefit from geoengineering and who will suffer? Moreover, who gets to decide this fate?[42] Recognizing this issue, the Royal Society, an independent scientific academy based in London, UK, has already recommended against the deployment of any geoengineering methods with impacts that extend beyond their geographic borders.[43]

In the case of SAM, computer modelling of and ongoing experimentation on the method have not yet shown adverse or unintended effects on places beyond the localized areas where SAM is used.[44] This makes SAM a more viable climate-altering technique than the aforementioned methods. However, garnering consent to use

SAM in said localized areas still remains an issue, as will be explored in the discussion of responsible research innovation.

Governing Geoengineering Technologies

Current Governance Frameworks

Knowing how to increase albedo and deploying it are two different matters. While SAM deployments at testing locations show promising results for the protection and promotion of ice cover, permits for its use are given on an individual basis by local landowners or corporations for the areas where SAM is tested.[45] Policy avenues for its quick and uniform deployment elsewhere are limited. Any adoption of SAM in Canada, for example, will require an examination of climate policies and perhaps even the creation of new policy frameworks entirely. Though geoengineering has increasingly entered into mainstream climate policy considerations, it is not fully embraced by all and remains an issue of contention in climate and policy realms.[46]

Climate change is transforming Canada's Arctic region and simultaneously transforming our interpretation and application of existing policies and laws, even calling attention to the lack of available science policy surrounding geoengineering technologies.[47] The following section will explore these gaps in policy and what the application of field research governance may look like for the adoption of SAM in Canada's Arctic.

International Governance Frameworks

Because SAM is intended for use in the Arctic, there is an additional layer of considerations that needs to be addressed for its responsible deployment. The Arctic is subject to a complex network of international treaties, federal laws, and territorial laws amidst its fragile environment. The Arctic is governed primarily through soft law instruments in conjunction with Canadian federal law.[48] A number of treaties would have to be carefully consulted for the responsible deployment of SAM. Below is a non-exhaustive list of treaties that may be of particular relevance to SAM. As will become apparent, most treaties acknowledge geoengineering in a broad sense or not at all. The duality of this makes SAM particularly hard to evaluate within the confines of international treaties.

The London Convention

The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, is an international agreement to control pollution of the seas and protect marine environments from human activity. The London Convention was amended to include marine geoengineering activities in 2013, which included the adding of Article 6bis which states, "Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in Annex 4, unless the listing provides that the activity or the sub-category of an activity may be authorized under a permit."[49] However, this amendment is not in force.[50] Marine geoengineering, in this case, is defined as "a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long-lasting or severe."[51] SAM is a deliberate intervention in the environment as a means of manipulating the current natural process of sea ice loss. However, the limitations of this amendment as it pertains to SAM are significant.

The Convention focuses primarily on marine geoengineering projects like ocean fertilization. It says little to nothing on its mandate to regulate other forms of geoengineering.[52] As such, it is difficult to determine if SAM would be subject to this Convention. However, SAM's intended introduction of silica microspheres on Arctic sea ice could trigger its categorization as marine dumping, which is defined as "any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea."[53] Yet, dumping does not include the "placement of matter for a purpose other than the mere disposal thereof…"[54] Therefore, it may be necessary for SAM to be assessed under the London Convention in order to be issued a permit, if deemed applicable. Permits for the dumping of matter at sea can be issued if an "adequate scientific basis exists concerning characteristics and composition of the matter to be dumped to assess the impact of the matter on marine life and on human health."[55] What constitutes an "adequate scientific basis" is at the discretion of the government issuing the permit. The ambiguity of SAM as an emerging technology, and as a geoengineering technique that introduces materials into the environment, makes the application of the London Convention to SAM both a significant and complex one. Perhaps most importantly, the non-binding nature of the London Convention leaves room for geoengineering technologies to proceed without being properly evaluated.

United Nations Convention on the Law of the Sea

The United Nations Convention on the Law of the Sea (UNCLOS) of 1982 is the international body that governs the maritime activities of all states. States that undertake maritime activities must have due regard for the interests of other states and comply with the Convention's scientific research and environmental protection articles. Of particular relevance to SRM activities, Article 192 of UNCLOS "creates a general obligation of environmental protection and preservation and the sovereign right of coastal states to exploit their natural resources,"[56] limited by their duty to protect and preserve marine environments.[57] Arguably, SAM protects and preserves marine environments by limiting the impacts of climate change, thereby protecting the Arctic ice cover and permafrost. However, the introduction of silica microspheres may also be interpreted as posing a danger to marine environments and animals. UNCLOS establishes an "obligation to take all measures to prevent, reduce and control pollution from *any* source."[58] This creates a conflict similar to that experienced with the London Convention. There is no explicit banning of geoengineering technologies; however, the impact of geoengineering, including SAM, could be argued either way. It is proposed as a means of saving our climate from the increasingly detrimental impacts of climate change, but there are a number of unknown side effects that could make it equally detrimental to the areas that cannot afford to implement geoengineering technologies. This makes it especially difficult to examine its compliance with NCLOS as an international treaty.

During the UNCLOS negotiations, Canada had advocated for the establishment of a special legal regime for ice-covered areas in order to protect against marine pollution and other harm to sensitive areas in the Canadian Arctic.[59] During the negotiations, it was determined that Arctic waters and ice-covered areas in the Arctic were synonymous. As a result, Article 234 was proposed and accepted in order to provide special controls to prevent marine pollution on ice-covered areas, underlining the need for the protection of the Arctic's sensitive environment.[60] The Article states that "Coastal States have the right to adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered areas within the limits of the exclusive economic zone…"[61] However, the prescribed purpose is limited to "the prevention, reduction and control of marine pollution from vessels,"[62] which would imply that SAM's deployment, if not from a marine vessel, would not be beholden to this Article. Additionally, the Article itself was not intended to regulate the Arctic where ice cover was diminishing. Having been created in 1982, UNCLOS had not considered or predicted the severity and rate of diminishing ice as a result of climate change and was therefore not intended to govern such areas.[63]

The Convention on Biological Diversity

The Convention on Biological Diversity (CBD) is the international legal instrument for "the conservation of biological diversity, the sustainable use of its components of biological diversity, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources."[64] On the topic of geoengineering, the Convention's scientific body, along with its ministers and the Conference of the Parties, agreed in 2010 that "in the absence of science based, global, transparent and effective control and regulatory mechanisms for geoengineering… no climate-related geoengineering activities that may affect biodiversity [will] take place, until there is adequate scientific basis on which to justify such activities."[65]

In the field research sites in which SAM is being carried out, ecotoxicology testing has been done on the silica microspheres that are used as reflective materials to increase albedo.[66] The spheres are dispersed in limited, strategic locations to act as a layer of ice. As they are dispersed in the natural environment, their contact with animals, aquatic life, and ecosystems is inevitable. The ecotoxicology information that is publicly available on the silica microspheres alleges that the materials are safe for humans, animals, and ecosystems alike. Animals and humans ingest silica, or sand, regularly. Important, however, is the fact that it does not bioaccumulate and therefore will not become concentrated inside the bodies of those that ingest it. Additionally, the silica microspheres, while quite small in size at approximately 35 micrometres on average, are still larger than 10 micrometres.[67] Anything below this threshold can be dangerous for inhalation as these particles cannot be properly filtered using natural physiological functions. In contrast, particles larger than 10 micrometres can be filtered out of the body through the respiratory tract if inhaled.[68] Further, the material is not chemically reactive, sticks to ice and water once deployed on their surface, does not attract oil-based pollutants, and is spherical so as to not cause damage with jagged edges.[69] Given its ecotoxicology report, SAM could have enough scientific basis to demonstrate that there is no harmful biological effects that would cause it to be in violation of the CBD. However, as per the Collingridge dilemma, harmful biological and other effects could become present as SAM is scaled up. Its impacts as a geoengineering technology cannot be properly assessed at the small-scale experimental level at which it presently exists. Treaties currently do not take into consideration the "net" effects of activities like geoengineering. That is, the immediate negative impacts of the activity may be outweighed by the prevention of future, more detrimental negative impacts.[70] In the case of SAM, introducing silica microspheres may not be a favourable act in the short term, but in the long term it could have exceedingly positive impacts on slowing and mitigating climate change effects. Most treaties evaluate specific impacts resulting from the introduction of substances or energy into the environment, without evaluating the method or technology itself.[71]

Canadian Governance Frameworks

Nationally, there has been little to no development of principles to govern SRM research activities. Discussions of SRM have been conducted by non-government organizations like the Carnegie Climate Geoengineering Governance Initiative (C2G2),[72] but at a level of conceptualization that does not lend itself to concrete developments in framework mechanisms for application to SRM projects in Canada. The two mechanisms that do exist and have been identified as governance mechanisms in this field are Environmental Impact Assessments (EIAs) and research boards.[73] However, the existing mechanisms were not built with geoengineering in mind, nor do they necessarily have the capabilities to assess such an innovative and contemporary technology. Therefore, EIAs and research boards may not have the capacity to fully and accurately evaluate the impacts of SRM. With new technology comes new complications.[74] Undoubtedly, EIAs and research boards will have gaps in their application to SRM. Therefore, the creation of a new governance mechanism may be needed to explore the possibilities and impacts of SRM, including SAM, in Canada.

Impact Assessments

In Canada, the *Impact Assessment Act* (S.C. 2019, s. 1) is the federal legislative basis for an Environmental Impact Assessment (EIA). Its purpose is to protect the environment from significant adverse environmental effects caused by proposed projects. All environmentally-relevant projects must undergo an assessment that includes consideration of: the environmental effects (including those caused by accidents), cumulative environmental effects, significance of environmental effects, public comments, mitigation measures and follow-up requirements, purpose of the project, alternatives to the project, any changes to the project during deployment, results of relevant regional studies, and other relevant matters.[75] As SAM is a project that would, as is intended, cause significant environmental impacts when deployed at a large scale, it would likely be designated for EIA. Even at a small scale, SAM's introduction of silica microspheres into the environment would be cause enough to require an EIA at an early stage.

The shortfall of any EIAs, however, is that they were not intended to be used for a technological evaluation of this form. While well suited to assessing local environmental impacts of oil and gas pipelines and waste management facilities, for example, the impacts of SRM are beyond the scope of EIAs.[76] Geoengineering field experiments often do not have real-world predecessors to make accurate predictions of environmental impacts in the short and long terms. This makes the ability to properly assess risk a challenge.[77] Additionally, predicting the indirect impacts of geoengineering, namely the social and ethical concerns, is not a facet available within traditional EIAs.[78] Therefore, a framework for assessing SRM throughout its deployment would be more appropriate as it would be more able to account for the different environmental impacts of SAM as it is scaled-up, not simply during a single phase in research. The impacts of SAM vary depending on the scale to which it is used; as such, a framework that recognizes this facet would need to be used for its assessment.

In Canada, impact assessments are carried out in the planning phase of a project and must take into account a number of factors including: "22(1)(a) the changes to the environment or to health, social or economic conditions and the positive and negative consequences of these changes that are likely to be caused by the carrying out of the designated project; (b) mitigation measures that are technically and economically feasible and that would mitigate any adverse effects of the designated project; (c) the impact that the designated project may have on any Indigenous group and any adverse impact that the designated project may have on the rights of the Indigenous peoples of Canada recognized and affirmed by section 35 of the *Constitution Act, 1982;* (d) the purpose of and need for the designated project; and (e) alternative means of carrying out the designated project that are technically and economically feasible, including through the use of best available technologies, and the effects of those means."[79] However, the *Impact Assessment Act*, like most EIAs, is not well equipped to examine every facet of SAM and SRM as a whole.

Responsible Conduct of Research

In Canada, the Tri-Agency Framework: Responsible Conduct of Research is the main regime for research ethics. The three federal research funding agencies that make up the Tri-Agency are: the Canadian Institute of Health Research (CIHR), the Social Sciences and Humanities Research Council of Canada (SSHRC), and the Natural Sciences and Engineering Research Council (NSERC).[80] The agency requirements for certain types of research include licenses for research in the field, which would be applicable to SAM experimentation.

Of particular relevance to SAM is the *Natural Sciences and Engineering Research Council Act* (R.S.C., 2985, c. N-21), or *NSERC Act*, which functions to "promote and assist research in the natural sciences and engineering, other than health sciences."[81] Research ethics and conduct boards could prove beneficial in the role of SRM governance as they function as transparency mechanisms. Subjecting SRM projects to research ethics could build trust and transparency around the technologies used.[82] However, council members are primarily made up of academics and academic administrators, which gives research agencies substantial independence in setting policies.[83] Thus, the *NSERC Act* and other research conduct boards fail to capture the considerations and consultation of the general public.

Currently, not much is publicly available on the research policy application to SAM projects. However, within Canada, SAM is being tested at the University of Manitoba's Sea Ice Environmental Research Facilities (SERF) in Winnipeg, Manitoba. As the research takes place within the University's facilities, it is likely that the project would have undergone Responsible Conduct of Research approval as per the University of Manitoba's Responsible Conduct of Research Policy, which states that the University "wishes to ensure the highest standards of integrity in all Research associated with the institution."[84] The issue with research ethics boards (REBs) when applied to SAM and other emerging technologies is that they do not have the tools needed to properly assess technology. REBs focus primarily on issues of privacy, consent, and impacts on human participants. While these issues are important, assessing SAM under REB alone would not fully capture all of the nuances of SAM's use and the varying impacts beyond humans alone. SAM and many other geoengineering technologies would likely pass REBs without concern since they do not involve the direct participation of humans and environmental impacts are often non-existent at small scales.[85] As per the Collingridge dilemma, many impacts do not become apparent until the technology is used at larger scale.[86]

One of the major limitations of EIA and REB application to SAM is that both examine the immediate impacts of a project rather than the long term. SAM's strategy is intended to create broader impacts over the long term, and these frameworks are poorly equipped to consider the broader impacts of SAM. While it might be applicable to the small-scale deployment of SAM in its current field-testing stage, SAM is ultimately meant to be deployed at a far larger scale, one that will have lasting and far-reaching impacts. Secondly, neither EIAs nor REBs consider the impacts of the development of the technology itself. The social, ethical, and political factors that need to be considered in the implementation of SAM cannot be captured by only one of the above governance frameworks that exist within Canada. Both are intended to examine the physical impacts rather than the ethical dimensions of geoengineering. SAM is an innovative technology that does not and cannot fit neatly into a category for evaluation of its merits and governance. EIAs and research ethics boards alone cannot capture the complicated, overlapping considerations that need to be addressed before SAM can be deployed in a way that is politically and environmentally aware and that properly involves consultation with the Canadian society it will impact.

Disadvantages of a Piecemeal Approach

There are a number of advantages to using already existing governance frameworks like international treaties and national research governing bodies for the governance of geoengineering technologies. However, because these frameworks were not made to address geoengineering directly—let alone the vastly different forms of geoengineering—there are far more disadvantages to their use when considering geoengineering itself. SRM experimentation, like that which is being done with SAM in Northern Manitoba, is subject to national laws. The scope and impact of field experimentation are not large enough to warrant the need for international treaty legislation mechanisms.[87] However, international treaties will become increasingly important as experiments are scaled up and technologies are deployed. The impact to the environment would be localized in such small-scale field-testing sites, as is the case with SAM. However, how these experiments are managed and governed at the small scale may impact how they are deployed when scaled up. Because of this, treaties should be important in informing any legal frameworks for the deployment of SAM nationally. Without a singular approach to SAM, and SRM governance more generally, it will be difficult to determine how and when scaling up experimentation is appropriate or safe within Canada. While EIAs and REBs may be able to regulate certain facets of SAM at its current small, experimental scale, they lack the ability and foresight to govern such a technology at a larger scale where the ethical dimensions of such technology need to be addressed. It should not be left to individual research ethics boards or impact assessments, as they cannot fully address all the possible impacts of SRM on humans and environments alike.

The function of geoengineering research like the SAM field-testing sites is to prevent and minimize harm. Additionally, the risk of harm caused by SAM experimentation is far smaller than the risk caused by climate change if no mitigation efforts are taken.[88] Geoengineering governance frameworks should take the same approach. Despite geoengineering falling into a number of international legal frameworks, as outlined by the non-exhaustive list above, none of them refer specifically to SAM or even SRM. The Convention on Biodiversity addresses geoengineering on a general scale and the London Convention is limited to ocean fertilization experiments. As is the case with many of the relevant national legal frameworks, international treaties are often technical and fail to address the social elements of geoengineering.[89] While addressing all the societal impacts of geoengineering is beyond the scope of this policy primer, it is such a crucial component of geoengineering that it cannot be overlooked when introducing legal and governing frameworks for its deployment.

Governing Surface Albedo Modification using a Responsible Innovation Framework

Like all geoengineering techniques, SAM is not a silver bullet solution for climate change. The assessment of geoengineering advantages and disadvantages is ongoing as the potential for use has only just begun gathering attention within political and public realms.[90] The potential for geoengineering to transform our environment begs the question: who is authorized to manipulate the climate?

Governing emerging and innovative technologies is a difficult task. The lack of cohesion between existing frameworks and the differences in governing bodies from national and international backgrounds makes a piecemeal governance approach a poor one for SAM. The following section will explore the use of a framework for responsible innovation proposed by Jack Stilgoe, Richard Owen, and Phil Macnaghten in their article "Developing a framework for responsible innovation," in the *Research Policy* journal. The framework, presented in 2013, supports the unity of policy and innovation to make policy more accessible to the innovative technology community through four integrated dimensions: anticipation, reflexivity, inclusion, and responsiveness.[91]

Responsible innovation, or responsible research and innovation (RRI), has roots in ideas for social, natural, and physical science collaborations and public engagement with science and technology. This concept was proposed for the integration of technology assessment and anticipatory governance,[92] both of which play an important role when discussing SAM's applications in Canadian climate technology solutions. RRI reflects the limitations of existing frameworks in governing emerging technologies in ethically challenging areas, such as geoengineering.[93] Similar to geoengineering technologies, RRI is a rapidly growing concept with uncertainty in its theoretical conceptualization and its transition into practice.[94] While SAM is an innovative model that produces knowledge and value for combatting climate change and its associated risks, it is also a project that produces ethical and moral dilemmas and unknown impacts in the short and long terms. It is impossible to predict the exact outcome of SAM if it were deployed on a large scale.

Geoengineering techniques are, at their core, emerging technologies. Their development and application are largely unrealized. Despite this, geoengineering, like most emerging and innovative technologies, is perceived as having the power to radically transform the existing social system and alter the status quo.[95] Further, emerging technologies are categorized by their rapid growth, prominent impacts, and uncertainty.[96] Based on this and the broad definition of responsible innovation as "taking care of the future through collective stewardship of science and innovation in the present,"[97] SAM falls under the category of RRI. For this reason, a responsible innovation framework could be the best method for governing SAM, an emerging technology.

<u>What Canada Can Do</u>

The steps that Canada can take will be examined in this section to demonstrate how Canada, as a host of SAM's research, can be a leader in the move towards responsible research innovation for technologies like geoengineering.

The Creation of a Dedicated Geoengineering Committee

The current research and proposed locations for the strategic employment of SAM demonstrate that Canada can reasonably anticipate that SAM will be scaled up in the near future. This also suggests that Canada should anticipate that other SRM technologies may also move towards deployment within national borders. In order to address this, an interdisciplinary advisory committee, similar to REBs, should be established with the sole purpose of reviewing and governing geoengineering research within Canada, overseeing their experimental research initiatives.[98] As a first step, this is a relatively easy early-stage approach to the governance of SRM that does not require taking political risk. Establishing a committee with an explicit and focused dedication to SRM governance could build the legitimacy of SRM research and any opportunities to scale up these technologies.[99]

This committee should be interdisciplinary in nature, including voices from academic, scientific, ethical, and political realms in order to evaluate risks through a number of lenses. As geoengineering is a technology that has potentially global impacts, voices from around the world should also be included, especially those who have largely been left out of the conversation surrounding climate change previously, including representation from low-income countries. This would expand SAM beyond simply scientific experimentation and into a holistic frame that considers moral responsibilities and sociological impacts on society as a whole.[100] This committee should meet a number of important characteristics in order to establish legitimacy as a world voice for geoengineering assessment. These characteristics include: establishing a mandate for organization, obtaining high-level authorization, including distinguished commissioners from broad fields and international backgrounds, and possessing adequate time and resources to properly carry out consultation, assessments, and recommendations.[101] As it stands currently, the Council of Canadian Academies (CCA), an organization that convenes experts in respective fields to assess evidence on complex scientific topics of public interest to inform decision-making in Canada,[102] fills a number of these requirements. As an already established council, the CCA has the potential to become a leader in geoengineering expertise and assessment. Importantly, if they were to undertake an assessment and evaluation of geoengineering, they would need to expand their current panel to include more international experts and voices. Including a number of stakeholders and taking a multidisciplinary approach to SAM at an early stage (before large-scale deployment) would make for a smoother transition into a wider governance framework strategy in the future.[103]

The Creation of a Code of Conduct

In order to ensure the uniform deployment of SAM and other SRM technologies, one aspect of the committee could be the creation of a code of conduct for SRM projects taking place within Canada. Canadian academic Anna-Maria Hubert from the University of Calgary has already drafted a *Code of Conduct for Responsible Geoengineering Research.*[104] Its expansion and use could be an important way to uniformly manage geoengineering technologies during their research phase. The Code of Conduct builds on existing legal sources like EIAs and rules of customary law in international treaties. As was established, though existing frameworks fall short for use in governing SAM, they offer an important framework for the creation of governance rules for SAM and SRM overall. The Code of Conduct for Canadian geoengineering research and experiments offers practical guidance on the responsible conduct of SRM while supporting knowledge sharing and mobilization to encourage best practices of said research.[105] As is important for responsible research innovation, this code should also be reflexive in that it is reviewed and changed frequently as new knowledge is obtained through experimentation and the research of SRM.

Public Engagement

In order to remain vigilant against unequal harm caused by SRM, Canada should implement public engagement avenues to promote public awareness and input. This could be done as part of the creation of a geoengineering committee and/or as part of the code of conduct. Canada can look towards the geoengineering case of Stratospheric Particle Injection for Climate Engineering (SPICE), carried out in the United Kingdom. The project, which was a funded research project aimed at allowing the UK to make "informed and intelligent assessments about the development of climate engineering technologies,"[106] brought together researchers from multiple backgrounds to address the research challenges within geoengineering.[107] While the project lacked ethical and social science evaluations, it did examine socio-political dimensions of SRM[108] and was informed by a public dialogue exercise.[109] There are a number of different ways that public engagement and input can be included in the use of geoengineering, including government-led processes or via non-governmental organizations (NGOs) and focus groups.[110] Most important is that public engagement be built into the scientific process of innovation in order to reflect citizens' concerns and include a wide variety of input when creating governance frameworks.[111] Offering inclusion in policymaking through a bottom-up, participatory approach reflects the social and cultural context of SRM within Canada.[112]

Conclusion

Arctic sea ice is decreasing at a drastic and increasingly rapid pace and the current climate mitigation strategies are falling short. The use of SAM as a means to protect Arctic sea ice and slow climate change, coupled with mitigation efforts, could protect the Arctic's crucial role in balancing the world's climate systems. Despite the contention that exists in the debate surrounding geoengineering, with each passing year the likelihood of climate-altering technologies being deployed to combat climate change increases.

The impacts of climate change are indisputable and the threat of climate change to Arctic sea ice is even more immediate, with estimates of an ice-free Arctic as soon as the 2030s being a very alarming reality.[113] Geoengineering technologies have increasingly been identified as potential remedial measures to mitigate and slow climate change. It is important that a governance framework, like responsible innovation frameworks, be implemented in anticipation of geoengineering deployment in order to manage innovative technologies in a way that can be adaptive to information as it is learned. Since geoengineering has not yet been deployed on a global scale, there is a lack of existing policy avenues that would allow for the quick, uniform, and safe deployment of SAM. There is clearly a need for policy cohesion among different governing bodies. Geoengineering does not just have environmental impacts; it also has social impacts, economic impacts, and ethical and moral issues. None of the existing governance frameworks can address all of these concerns. Therefore, a new framework specifically designed to address all the intersecting issues affected by SAM and geoengineering as a whole is overdue.

Climate change is transforming the world and drastically transforming the Arctic in particular. Simultaneously, climate change is altering our interpretation and application of existing policies and laws.[114] Even when coupled with international environmental treaties, national environmental impact assessments and responsible research codes are not enough to address all the complexities of governing geoengineering. What is available is not enough. It is clear that the creation and implementation of a governance framework intended to adaptively manage the use of climate-altering technologies in Canada and abroad is necessary. One hopeful aspect is that Canada has the opportunity to take steps towards creating an inclusive and responsible governance framework for SAM and SRM as a whole. While there may be risks to utilizing and deploying SAM, the risk of doing nothing may prove to be far worse as climate change continues to cause increasingly detrimental impacts around the world.

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