CIGI PAPERS
NO. 111 — OCTOBER 2016

THE PARIS AGREEMENT AND CLIMATE GEOENGINEERING GOVERNANCE

THE NEED FOR A HUMAN RIGHTS-BASED COMPONENT

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ABOUT THE ILRP

The International Law Research Program (ILRP) at CIGI is an integrated multidisciplinary research program that provides leading academics, government and private sector legal experts, as well as students from Canada and abroad, with the opportunity to contribute to advancements in international law.

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ABOUT THE AUTHOR

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William is the former president of the Association of Environmental Studies and Sciences, as well as co-chair of the International Environmental Law interest group of the American Society of International Law. Prior to becoming an academic, William served as assistant secretary of state for public affairs for the State of Wisconsin and worked in the non-governmental sector for 20 years, including as executive director of the Pacific Center for International Studies, a think tank that focused on implementation of international wildlife treaty regimes, including the Convention on Biological Diversity and International Convention for the Regulation of Whaling.

William has published more than 75 articles in law, science and policy journals and has co-edited four books. His current areas of research focus are: climate geoengineering; international climate change litigation; adaptation strategies to address climate change, with a focus on the potential role of microinsurance; the effectiveness of international treaty regimes to conserve cetaceans; and how to effectively operationalize the precautionary principle in international environmental treaty regimes. William holds a Ph.D. in international environmental law from the University of Wales-Cardiff School of Law.

ACRONYMS AND ABBREVIATIONS

ASEAN	Association of Southeast Asian Nations
BECCS	bioenergy with carbon capture and storage
CCS	carbon capture and sequestration
CDR	carbon dioxide removal
COP	Conference of the Parties
CRC	Convention on the Rights of the Child
CROZEX	CROZet Natural Iron Bloom and EXport Experiment
DAC	direct air capture
ECHR	European Convention for the Protection of Human Rights and Fundamental Freedoms
EIA	environmental impact assessment
GCM	general circulation model
GeoMIP	Geoengineering Model Intercomparison Project
GBEP	Global Bioenergy Partnership
GHGs	greenhouse gases
HRBA	human rights-based approach
HRIA	human rights impact assessment
ICCPR	International Covenant on Civil and Political Rights
ICESCR	International Covenant on Economic, Social and Cultural Rights
INDC	intended nationally determined contribution
IPCC	Intergovernmental Panel on Climate Change
LDCs	least developed countries
NETs	negative emissions technologies
OHCHR	Office of the UN High Commissioner on Human Rights
SAI	sulphur aerosol injection
SBI	Subsidiary Body for Implementation
SBSTA	Subsidiary Body for Scientific and Technological Advice
SRM	solar radiation management
UDHR	Universal Declaration of Human Rights
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNHRC	United Nations Human Rights Council
WMO	World Meteorological Organization

SYMBOLS

GtC	gigatons carbon
$GtCO_2$	gigatons carbon dioxide
µm	micrometre
TgS	teragrams sulphur
W/m^2	watts per square metre

EXECUTIVE SUMMARY

There has been growing recognition in the past decade at both the international and domestic levels of the potential ramifications of climate change for the exercise of human rights. Even more recently, the locus of concern has expanded to include the human rights implications of response measures to confronting climate change. The newly adopted Paris Agreement includes language that calls on its parties to consider, respect and promote the protection of human rights when taking actions to address climate change. However, the agreement fails to suggest specific means to operationalize this mandate.

This paper suggests a framework for achieving the objective of protecting human rights in the context of climate change response measures. It focuses on one suite of emerging potential measures that fall under the general rubric of "climate geoengineering," which is defined as efforts to effectuate large-scale manipulation of the planetary environment through technological options in order to counteract the manifestations of climate change. The paper suggests that the parties to the Paris Agreement utilize a human rights-based approach (HRBA) as a framing mechanism to ensure that the potential human rights implications of climate geoengineering options are assessed in the policy-making process moving forward. Such an approach may help to ensure that any potential negative ramifications of climate geoengineering options on the human rights interests of the world's most vulnerable peoples are taken into account and minimized. Moreover, this analysis might help us to flesh out more broadly the contours of the new human rights language in the Paris Agreement.

INTRODUCTION

In the past decade, there has been increasing recognition in both the human rights and climate change communities of the profound, and largely adverse, impacts that climate change may have on the exercise of human rights.[1] More recently, the ambit of concern has expanded to the potential impacts that *response measures* to climate change might have on human rights. For example, at the 16th Conference of the Parties (COP) to the UNFCCC,[2] a resolution was adopted providing that the parties "should, in all *climate change related actions*, fully respect human rights."[3] The Kyoto Protocol's[4] Adaptation Fund Board, in its Environmental and Social Policy guidelines, also provides that "Projects/programmes supported by the Fund shall respect and where applicable promote human rights."[5] Human rights bodies have similarly emphasized the need to respect human rights when addressing the threat of climate change. In terms of human rights institutions, the UN's Office of the High Commissioner for Human Rights (OHCHR) in 2009 emphasized that "human rights standards and principles should inform and strengthen policy measures in the area of climate change."[6]

Most recently, in December 2015, the parties to the UNFCCC adopted the text of the Paris Agreement,[7] a legal instrument designed to respond to "the need for an effective and progressive response to the urgent threat of climate change."[8] As the UNHRC recently observed, "the Paris Agreement is the first climate agreement, and one of the first environmental agreements of any kind, to explicitly recognize the relevance of human rights."[9] Its preambular language provides: "Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity."[10]

It is laudable that the drafters of the Paris Agreement recognized that programs and actions to address climate change can have human rights implications and that every effort should be made to ameliorate such impacts. However, as Basil Ugochukwu recently observed, there is an immediate need to translate this provision "in ways that integrate human rights into practical actions in specific climate change policies."[11]

1 United Nations Human Rights Council [UNHRC], *Human Rights and Climate Change,* HRC Res 29/15, UNHRCOR, 29th Sess, UN Doc A/HRC/RES/29/15 (2 July 2015), online: <https://daccess-ods.un.org/TMP/8490088.58203888.html>. "Affirming that human rights obligations, standards and principles have the potential to inform and strengthen international, regional and national policymaking in the area of climate change"; UNHRC, *Human Rights and Climate Change,* HRC Res 26/27, UNHRCOR, 26th Sess, UN Doc A/HRC/RES/26/27 (15 July 2014), online: <https://daccess-ods.un.org/TMP/2523183.22658539.html>. "Emphasizing that the adverse effects of climate change have a range of implications, both direct and indirect, for the effective enjoyment of human rights"; UNHRC, *Human Rights and Climate Change,* HRC Res 10/4, UNHRCOR, 10th Sess, UN Doc A/HRC/RES/10/4 (3 March 2009), online: <ap.ohchr.org/documents/E/HRC/resolutions/A_HRC_RES_10_4.pdf>. "Climate change-related impacts have a range of implications, both direct and indirect, for the effective enjoyment of human rights"; United Nations Framework Convention on Climate Change [UNFCCC], *The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention*, FCCC Dec 1/CP.16, UNFCCC, 2010, UN Doc FCCC/CP/2010/7/Add.1 (2010), at para 8, online: <unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf> [*The Cancun Agreements*]. Parties "should, in all climate change related actions, fully respect human rights"; Mary Robinson Foundation, *Incorporating Human Rights into Climate Action,* Version 1 (October 2014), at 4, online: <www.mrfcj.org/pdf/2014-10-20-Incorporating-Human-Rights-into-Climate-Action.pdf>. Forty-nine parties to the UNFCCC have made explicit references to human rights in their National Communications or National Adaptation Plans of Action.

2 UNFCCC, 9 May 1992, 1771 UNTS 107, 31 ILM 849 (entered into force 21 March 1994).

3 *The Cancun Agreements, supra* note 1 at para 8 [emphasis added]. While not explicitly referring to human rights impacts, the Kyoto Protocol to the UNFCCC includes concordant language, providing that industrialized countries should strive to "minimize adverse social, environmental and economic impacts on developing country Parties" in terms of mitigation response measures. Kyoto Protocol to the United Nations Framework Convention on Climate Change, 10 December 1997, 2303 UNTS 148, 37 ILM 22 art 3(14) (entered into force 16 February 2005) [Kyoto Protocol].

4 Kyoto Protocol, *supra* note 3.

5 Adaptation Fund Board, *Environmental and Social Policy* (November 2013), at para 15, online: <www.adaptation-fund.org/wp-content/uploads/2015/09/Environmental-Social-Policy-approved-Nov2013.pdf>.

6 UNHRC, *Report of the Office of the United Nations High Commissioner for Human Rights on the relationship between climate change and human rights*, 15 January 2009, UN Doc A/HRC/10/61 at para 75, online: <www.ohchr.org/Documents/Press/AnalyticalStudy.pdf>.

7 UNFCCC, COP, Paris Agreement to the United Nations Framework Convention on Climate Change, 12 December 2015, Dec CP.21, 21st Sess, UN Doc FCCC/CP/2015/L9, online: <unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf> [Paris Agreement].

8 *Ibid*, Preamble.

9 UNHRC, *Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment*, 1 February 2016, 31st Sess, UN Doc A/HRC/31/52 at 6, online: <www.ohchr.org/EN/HRBodies/HRC/RegularSessions/Session31/Documents/A%20HRC%2031%2052_E.docx>.

10 Paris Agreement, *supra* note 7, Preamble.

11 Basil Ugochukwu, *Climate Change and Human Rights: How? Where? When?,* CIGI, CIGI Papers No. 82, 27 November 2015 at 9. See also International Human Rights Law Clinic, Miller Institute for Global Challenges and the Law, University of California, Berkeley, School of Law & Center for Law & Global Justice, University of San Francisco, School of Law, "Protecting People and the Planet" (December 2009) at 7, online: <https://repositories.lib.utexas.edu/bitstream/handle/2152/7464/Protecting_People_and_the_Planet-Berkeley.pdf?sequence=2&isAllowed=y>.

This paper seeks to develop a framework for operationalizing the Paris Agreement's human rights language in the context of an emerging potential response to climate change, a suite of technological options denominated as "climate geoengineering." It is hoped that this exercise may help to inform efforts to develop guidelines for considering the human rights implications of other climate-related response measures in the future, including in the context of mitigation and adaptation.

Climate geoengineering is defined by the United Kingdom's Royal Society as "the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change."[12] As a number of commentators have noted, climate geoengineering could prove to be the most imposing global governance challenge of the next few decades.[13] This is primarily because it could create both winners and losers in terms of its impacts.[14] While this paper agrees with commentators who have expressed the need for the establishment of a comprehensive international governance framework for climate geoengineering,[15] fleshing out its contours is beyond the scope of this paper. Rather, the purpose here is to suggest that a human rights-based approach may constitute a critical component in addressing intrinsic issues of equity and justice that would necessarily arise should the world community opt to proceed down this path.[16] In developing this argument, this paper provides an overview of climate geoengineering options; discusses the potential human rights implications of climate geoengineering, including within the context of the Paris Agreement; and develops a human rights-based approach to operationalizing the human rights provisions of the Paris Agreement in the context of climate geoengineering options.

OVERVIEW OF CLIMATE GEOENGINEERING

The Exigency for Climate Geoengineering

The Paris Agreement establishes the objective of "[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels...."[17] However, the emissions reduction pledges made by the parties to the UNFCCC to date, denominated as Intended Nationally Determined Contributions (INDCs) prior to the Paris Agreement[18] and termed Nationally Determined Contributions in the agreement,[19] are wholly inadequate to meet this goal. Indeed, the globe is currently on track for temperature increases between 2.6 and 3.7°C by 2100,[20] with even much higher temperatures over the course of centuries

12 The Royal Society, "Geoengineering the climate: science, governance and uncertainty (2009) at 11, online: <royalsociety.org/Geoengineering-the-climate/>.

13 Mason Inman, "Planning for Plan B" (17 December 2009) Nature Reports; Climate Change, online: <www.nature.com/climate/2010/1001/full/climate.2010.135.html>; Scott Barrett, "Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology" (2014) 8:2 Rev Envtl Econ & Pol'y 249 at 266.

14 Robert L Olson, "Geoengineering for Decision Makers" (November 2011) Woodrow Wilson International Center for Scholars at 16, online: <https://www.wilsoncenter.org/sites/default/files/Geoengineering_for_Decision_Makers_0.pdf>; Toby Svoboda et al, "Sulfate Aerosol Geoengineering: The Question of Justice" (2011) 25:3 Public Aff Q 157 at 165.

15 "A Charter for Geoengineering", Editorial, (2012) 485 Nature 415 at 415; John Virgoe, "International Governance of a Possible Geoengineering Intervention to Combat Climate Change" (2009) 95 Climatic Change 103 at 119 [Virgoe].

16 Richard Owen, "Solar Radiation Management and the Governance of Hubris" (2014) 38 Issues in Environmental Science & Technology 212 at 220; Michael Burger & Jessica Wentz, Climate Change and Human Rights (2015) United Nations Environment Program [UNEP] at 10, online: <apps.unep.org/publications/index.php?option=com_pub&task=download&file=011917_en>.

17 Paris Agreement, *supra* note 7, art 2(1)(a).

18 See UNFCC, *Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013*, Dec 1/CP.19 Further advancing the Durban Platform, UN Doc FCCC/CP/2013/10/Add.1 at para 2(b), online: <unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf> [Durban Platform]; UNFCC, INDCs as communicated by Parties, online: <www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

19 Paris Agreement, *supra* note 7, art 4(2).

20 Joeri Rogelj et al, "Paris Agreement Climate Proposals Need a Boost to Keep Warming Well Below 2°C" (2016) 534 Nature 631 at 634; Climate Action Tracker, "Paris Agreement: stage set to ramp up climate action" (12 December 2015), online: <climateactiontracker.org/news/257/Paris-Agreement-stage-set-to-ramp-up-climate-action.html>; World Resources Institute, "Why are INDC Studies Reaching Different Temperature Estimates?" (2015), online: <www.wri.org/blog/2015/11/insider-why-are-indc-studies-reaching-different-temperature-estimates>. It should be emphasized that the *Paris Agreement* does provide for a "global stocktake" every five years "to assess the collective progress towards achieving the purpose of this Agreement and its long-term goals," with an eye to enhancing domestic and international commitments to meet the agreement's overarching objectives, if necessary; *Paris Agreement, supra* note 7 at art 14. While this provision could help the parties to avoid passing the 2°C threshold, this would require strengthened commitments prior to the agreement entering in force and more ambitious long-term commitments; Wolfgang Obergassel et al, *Phoenix from the Ashes — An Analysis of the Paris Agreement to the United Nations Framework Convention on Climate Change* (January 2016), online: Wuppertal Institute for Climate, Environment and Energy <wupperinst.org/uploads/tx_wupperinst/Paris_Results.pdf> at 45. The world's remaining "carbon budget" to avert passing the 2°C threshold may also be far lower than many current estimates given uncertainties about many critical parameters; Glen Peters, "The 'Best Available Science' to Inform 1.5°C Policy Choices" advance online publication: (11 April 2016) Nature Climate Change, DOI: <10.1038/nclimate3000>, online: www.nature.com/nclimate/journal/vaop/ncurrent/pdf/nclimate3000.pdf at 1.

and millennia beyond.[21] Temperature increases of this magnitude could have extremely serious implications for both natural ecosystems and human institutions.[22]

The spectre of climatic impacts of this magnitude has led to increasing recent interest in climate geoengineering options. Climate geoengineering proposals date back to the 1830s.[23] Yet, until the past decade, geoengineering was viewed as "a freak show in otherwise serious discussions of climate science and policy."[24] However, the feckless response of the world community to climate change has transformed climate geoengineering from a fringe concept to a potentially mainstream policy option.[25] Within the last decade, committees in both the US Congress and UK Parliament have conducted hearings on climate geoengineering and called for government-funded research programs.[26] In the case of the UK House of Commons, Science and Technology Committee, a recommendation was tendered for development of a regulatory framework.[27] Moreover, two international regimes, the Convention on Biological Diversity and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, have responded to ocean-based geoengineering research initiatives by issuing regulatory guidelines for prospective research.[28]

On the scientific side of the equation, small research programs on geoengineering options have been launched in several regions of the world, including the United States,

21 Carolyn W Snyder, "Evolution of Global Temperature Over the Past Two Million Years" (2016) Nature, doi: <10.1038/nature19798>: Even stabilization of atmospheric concentrations of GHGs at current levels could result in eventual warming of 5°C; Peter U Clark et al, "Consequences of Twenty-First Century Policy for Multi-Millennial Climate and Sea-Level Change" (2016) 6 Nature Climate Change 360 at 361.

22 UNFCCC, "Climate Change 2014, Synthesis Report, Summary for Policymakers" (2014), online: www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf at 18, 19; Durban Platform, *supra* note 18; INDCs as Communicated by Parties, *supra* note 18; V Ramanathan & Y Feng, "On Avoiding Dangerous Anthropogenic Interference with the Climate System: Formidable Challenges Ahead" (2008) 105:3 Proceedings National Academy Sci 14245 at 14245.

23 William CG Burns & Jane A Flegal, "Climate Geoengineering and the Role of Public Deliberation: A Comment on the US National Academy of Sciences' Recommendations on Public Participation" (2015) 5 Climate L 252 at 254.

24 David G Victor, "On the Regulation of Geoengineering" (2008) 24:2 Oxford Rev Econ Pol'y 322 at 323. The concept of climatic geoengineering extends back to at least the 1830s when American meteorologist J. P. Espy suggested that lighting huge fires could stimulate convective updrafts and alter the intensity and frequency of precipitation. Philip J Rasch et al, "An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols" (2008) 366 Philosophical Transactions Royal Soc'y 4,007 at 4,008. For a thorough historical treatment of weather and climate modification initiatives, see James Rodger Fleming, "The Pathological History of Weather and Climate Modification: Three Cycles of Promise and Hype" (2006) 37:1 Historical Stud in Physical Sci 3-25, online: <www.colby.edu/sts/06_fleming_pathological.pdf>.

25 Robin Gregory, Terre Satterfield & Ariel Hasell, "Using Decision Pathway Surveys to Inform Climate Engineering Policy Choices" (2016) 113 Proceedings Natl Acad Sci 560 at 560; Shinichiro Asayama, "Catastrophism Toward 'Opening Up' or 'Closing Down'? Going Beyond the Apocalyptic Future and Geoengineering" (2015) 63:1 Current Sociology 89 at 90. For a history of geoengineering over the past 50 years, *see* Wil Burns & Simon Nicholson, "Governing Climate Geoengineering" in Simon Nicholson & Sikina Jinnah, eds, *New Earth Politics* (Cambridge, MA: MIT Press, 2016) 345.

26 US, US House Committee on Science and Technology and a Recommendation by the Chair for a Geoengineering Research Agenda, "Engineering the Climate: Research Needs and Strategies for International Coordination" (October 2010), online: <democrats.science.house.gov/sites/democrats.science.house.gov/files/10-29%20Chairman%20Gordon%20Climate%20Engineering%20report%20-%20FINAL.pdf> at ii; UK, HC, Science and Technology Committee, "The Regulation of Geoengineering: Fifth Report of Session 2009-10" (10 March 2010), online: <www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/221.pdf> at 27 [UK Science and Technology Committee].

27 UK Science and Technology Committee,*supra* note 26.

28 The parties to the Convention on Biological Diversity at the 9th meeting of the Conference of the Parties in 2008 passed a resolution calling on the parties "to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities... with the exception of small scale scientific research studies within coastal waters." UNEP, Convention on Biological Diversity, *Decision adopted by the Conference of the Parties to the Convention on Biological Diversity: IX/16 Biological diversity and climate change,* UN Doc UNEP/CBD/COP/DEC/IX/16 (May 2008) online: <dcgeoconsortium.org/wp-content/uploads/2014/07/CBD-COP-9-Resolution.pdf> at para 4. For further information on ocean fertilization climate geoengineering, see Ocean Iron Fertilization, *infra*. In 2010, the parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, and its Protocol, passed a resolution adopting an assessment framework for scientific research in context of ocean fertilization: International Maritime Organization, Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, *Resolution LC-LP.2 (2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization*, Third-Second Consultative Meeting of the Contracting Parties to the London Convention and the Fifth Meeting of the Contracting Parties to the London Protocol (14 October 2010), online: <dcgeoconsortium.org/wp-content/uploads/2014/07/LC-Resolution-2010.pdf> at para 1; International Maritime Organization, Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, *Assessment Framework for Scientific Research Involving Ocean Fertilization* (2010), online: <dcgeoconsortium.org/wp-content/uploads/2014/07/LC-Geo-Assessment-Framework-2010.pdf>. In 2013, the parties to the *London Protocol* amended the agreement to make the risk assessment procedure legally binding on all of its parties, as well as to potentially extend the regulatory purview of the protocol to other marine-based geoengineering options: International Maritime Organization, London Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, *Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities* (2013), online: <dcgeoconsortium.org/wp-content/uploads/2014/07/resolution_lp_48.pdf>.

Europe and Asia.[29] Two extremely influential national scientific bodies, the United Kingdom's Royal Society and the US National Academy of Sciences, have also called for national research programs.[30] Moreover, the US Senate Appropriations Committee, in its latest spending bill, has proposed an unspecified level of funding for climate geoengineering research.[31] Also, the Intergovernmental Panel on Climate Change (IPCC), in its most recent assessment report, extensively discussed climate geoengineering options,[32] characterizing them as potential "emergency responses...in the face of potential extreme impacts."[33] Moreover, the new chair of the IPCC, Hoesung Lee, has advocated research on climate geoengineering options, including governance considerations.[34]

Climate Geoengineering Technologies

Climate geoengineering technologies are usually divided into two broad categories: solar radiation management (SRM) approaches and carbon dioxide removal (CDR) approaches.[35] This section seeks to describe each option in terms of their approaches to addressing climate change.

SRM TECHNOLOGIES

The sun ultimately drives the earth's climate, including the circulation of the world's oceans and atmosphere, by emitting energy, largely in the form of short-wave radiation.[36] Approximately two percent of incoming solar radiation reaching the earth (342 W/m^2) is absorbed by stratospheric ozone, 17 percent by aerosols and clouds in the troposphere, and 51 percent by the earth's surface. Thirty percent of solar radiation is subsequently emitted back to space through scattering and reflection by clouds, ice, snow, sand and other reflective surfaces.[37] The remaining 70 percent is absorbed by oceans, the atmosphere and land, and, as they re-radiate their absorbed energy, heat is released in the form of long-wave, or infrared, radiation at wavelengths of greater than 1.5 µm.[38]

While the atmosphere is transparent to short-wave radiation, it is opaque to long-wave, infrared radiation due to the presence of trace gases found naturally in the atmosphere, including water vapour, carbon dioxide,

29 Institute for Advanced Sustainability Studies, "European Transdisciplinary Assessment of Climate Engineering (EuTRACE)", online: <www.iass-potsdam.de/en/research-clusters/sustainable-interactions-atmosphere/climate-engineering/eutrace>; Eli Kintisch, *Bill Gates Funding Geoengineering Research*, Science (26 January 2010), Science, online: <www.sciencemag.org/news/2010/01/bill-gates-funding-geoengineering-research>; Cao Long et al, "Geoengineering: Basic Science and Ongoing Research Efforts in China" (2015) 6 Advances in Climate Change Research 188.

30 The Royal Society, *supra* note 12 at ix; National Research Council, US National Academy of Sciences, *Climate Intervention: Reflecting Sunlight to Cool Earth* (2015), online: www.nap.edu/catalog/18988/climate-intervention-reflecting-sunlight-to-cool-earth at 6; National Research Council, US National Academy of Sciences, *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration* (2015), online: www.nap.edu/catalog/18805/climate-intervention-carbon-dioxide-removal-and-reliable-sequestration at 107.

31 Adrian Cho, "To Fight Global Warming, Senate Calls for Study of Making Earth Reflect More Light, Science" (19 April 2016), online: <www.sciencemag.org/news/2016/04/fight-global-warming-senate-calls-study-making-earth-reflect-more-light>. The bill, S 2084, *inter alia*, calls for the Department of Energy to study the US National Academy of Science's 2015 Report on "albedo modification," one of the two broad categories of climate geoengineering (see the section on Potential Risks Associated with Climate Geoengineering *infra*), and to "leverage existing computational and modeling capabilities to explore the potential impacts of albedo modification." US, Bill S 2084, *Energy and Water Development Appropriations Bill, 2017,* 114th Cong, 2015-16.

32 IPCC, Working Group I Contribution on Fifth Assessment Report of the Intergovernmental Panel on Climate Change, *Climate Change 2013: The Physical Science Basis* (2013), online: www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf at 29; IPCC, Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate, *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects* (2014), online: <www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-PartA_FINAL.pdf> at 92; IPCC, Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, *Climate Change 2014: Mitigation of Climate Change* (2014), online: <www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf> at 256.

33 *Climate Change 2014: Mitigation of Climate Change*, *supra* note 32 at 41.

34 Suzanne Goldenberg, "UN Climate Science Chief: It's Not Too Late to Avoid Dangerous Temperature Rise", *The Guardian*, (11 May 2016), online: <www.theguardian.com/environment/2016/may/11/un-climate-change-hoesung-lee-global-warming-interview>.

35 William CG Burns, "Geoengineering the Climate: An Overview of Solar Radiation Management Options" (2012) 46 Tulsa L Rev 283 at 286. Alternatively, some commentators divide climate geoengineering options into "short-wave" and "long-wave" approaches. See TM Lenton & NE Vaughan, "The Radiative Forcing Potential of Different Climate Geoengineering Options" (2009) 9 Atmospheric Chemistry & Physics 5539 at 5540. It should be emphasized, however, that some approaches denominated as "geoengineering," including some carbon dioxide removal options, are closely akin to technologies for industrial carbon management, such as carbon capture and sequestration or land use, land use change and forestry, and, thus, might not be classified by everyone as "climate geoengineering." Virgoe, *supra* note 15 at 104.

36 National Oceanographic & Atmospheric Administration, Earth System Research Laboratory, "The Earth's Atmosphere", online: <www.esrl.noaa.gov/gmd/outreach/carbon_toolkit/basics.html>.

37 J Feichter & T Leisner, "Climate Engineering: A Critical Review of Approaches to Modify the Global Energy Balance" (2009) 176 Eur Physical J 81 at 82.

38 *Ibid*; John T Hardy, *Climate Change: Causes, Effects and Solutions* (Hoboken, NJ: Wiley, 2003) at 7.

methane and nitrous oxide.[39] These so-called "greenhouse gases" (GHGs) radiate back approximately 83 percent of infrared radiation,[40] spreading heat back to land and the oceans, and substantially warming the lower atmosphere. In the absence of this natural greenhouse effect, the average temperature on earth would decline from 57°F to –2.2°F, radically altering life on earth.[41]

For the 10,000 years prior to the mid-nineteenth century, the globe's temperature was relatively steady at 14°C (57°F).[42] However, burgeoning emissions of anthropogenic GHGs[43] have upset the earth's climate equilibrium, slightly restricting the emission of heat radiation to space.[44] To restore this imbalance, the lower atmosphere has warmed, resulting in the emission of more heat in the form of long-wave radiation. This has resulted in an increase in global temperatures of approximately 1°C since the pre-industrial era.[45] This is termed the "enhanced greenhouse effect."[46] With atmospheric GHG emissions reaching levels "unprecedented in at least 800,000 years,"[47] temperatures have been pushed to levels that increasingly threaten ecosystems and human institutions.

SRM methods focus on reducing the amount of solar radiation absorbed by the earth (pegged at approximately 235 W/m^{-2} currently)[48] by an amount sufficient to offset the increased trapping of infrared radiation by rising levels of GHGs.[49] Balancing positive global mean radiative forcing of +4 W/m^2, projected with a doubling of carbon dioxide from pre-industrial levels, would require reducing solar radiative forcing by approximately 1.8 percent.[50] Even a one percent reduction in forcing would have a substantial impact, producing a radiative forcing of –2.35 W/m^2.[51] Recent studies indicate that deployment of SRM approaches could begin to return temperatures to pre-industrial levels within a few years of deployment[52] and potentially restore temperatures to said conditions by the end of this century.[53]

SRM schemes can be subdivided into two categories: those that seek to reduce the amount of solar radiation reaching the top of the atmosphere and those that seek to reflect solar radiation within the atmosphere (tropospheric-based or in the tropopause and above) or at the surface.[54] The following sections briefly discuss the most frequently discussed SRM options.

39 Climate Central, "What is the greenhouse effect?" (7 November 2009), online: <www.climatecentral.org/library/faqs/what_is_the_greenhouse_effect>. Radiation from the sun peaks at a wavelength in the range of 0.4–0.7 µ, with small amounts of ultraviolet radiation down to 0.1 µ and small amounts of infrared radiation in the range of 3 µ. The earth, being much cooler, radiates energy at 15°C, with radiation emanation from ranges of 4–100 µ. Martin M Halmann & Meyer Steinberg, *Greenhouse Gas Carbon Dioxide Mitigation* (Boca Raton, FL: Lewis Publishers, 1999) at 1.

40 Hardy, *supra* note 38 at 8.

41 Julie Kerr Caspar, *Changing Ecosystems: Effects of Global Warming* (New York, NY: Facts on File, 2010).

42 Donald Kennedy & John A Riggs, eds, *U.S. Policy and the Global Environment* (Washington, DC: The Aspen Institute, 2000) at 11.

43 Carbon dioxide emissions, primarily linked to fossil fuel production, industrial processes and land-use change, have increased over 140 percent from pre-industrial levels. Methane emissions, with anthropogenic sources associated with ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning, have increased 254 percent from pre-industrial levels. Nitrous oxide emissions have increased 121 percent from pre-industrial levels, with anthropogenic sources including soils, ocean, biomass burning, fertilizer use and industrial processes. Other anthropogenic GHGs contributing to warming include sulphur hexafluoride, chlorofluorocarbons and halogenated gases, as well as hydrochlorofluorocarbons and hydrofluorocarbons; World Meteorological Organization [WMO] & Global Atmosphere Watch (9 November 2015) 11 WMO Greenhouse Gas Bulletin (November 2015), online: <library.wmo.int/pmb_ged/ghg-bulletin_11_en.pdf>. See also US Environmental Protection Agency, "Global Greenhouse Gas Emissions Data", online: <www3.epa.gov/climatechange/ghgemissions/global.html>.

44 Rasmus E Benestad, "A Mental Picture of the Greenhouse Effect" (21 January 2016) Theoretical Applied Climatology 3, DOI: <10.1007/s00704-016-1732-y>, online: <link.springer.com/article/10.1007/s00704-016-1732-y/fulltext.html>.

45 Steve Connor, "Global warming: World already halfway towards threshold that could result in dangerous climate change, say scientists", *Independent* (9 November 2015), online: <www.independent.co.uk/environment/climate-change/climate-change-global-average-temperatures-break-through-1c-increase-on-pre-industrial-levels-for-a6727361.html>.

46 Australia, Department of the Environment and Energy, "Enhanced Greenhouse Effect", online: <www.environment.gov.au/climate-change/climate-science/greenhouse-effect>.

47 WMO, "Atmospheric Concentrations of the Greenhouse Gases that Cause Climate Change Continue to Rise", online: <www.wmo.int/media/content/atmospheric-concentrations-greenhouse-gases-cause-climate-change-continue-rise>.

48 JT Kiehl & Kevin E Trenberth, "Earth's Annual Global Mean Energy Budget" (1997) 78:2 Bull American Meteorological Soc'y 197 at 198 (1997), online: <climateknowledge.org/figures/Rood_Climate_Change_AOSS480_Documents/Kiehl_Trenberth_Radiative_Balance_BAMS_1997.pdf>.

49 Michael C MacCracken, "Beyond Mitigation: Potential Options for Counter-Balancing the Climatic and Environmental Consequences of the Rising Concentrations of Greenhouse Gases" (2009), World Bank Policy Research Working Paper at 15, online: <elibrary.worldbank.org/doi/abs/10.1596/1813-9450-4938>.

50 The Royal Society, *supra* note 12 at 23.

51 *Ibid.*

52 *Ibid* at 34.

53 David P Keller, Ellias Y Feng & Andreas Oschlies, "Potential Climate Engineering Effectiveness and Side Effects During a High Carbon Dioxide-Emission Scenario" (25 February 2014) Nature Communications at 5–6, online: <www.nature.com/ncomms/2014/140225/ncomms4304/pdf/ncomms4304.pdf>.

54 Lenton & Vaughan, *supra* note 35 at 5540.

Sulphur Aerosol Injection

Sulphur aerosol injection (SAI) is considered the most technologically feasible geoengineering option, and thus the most actively investigated currently.[55] SAI seeks to enhance planetary albedo (surface reflectivity of the sun's radiation)[56] through the injection of a gas such as sulphur dioxide or another gas that will ultimately react chemically in the stratosphere to form sulfate aerosols. Alternatively, this approach may be effectuated through direct injection of sulphuric acid.[57] The high reflectivity of aerosols causes a negative forcing that could ultimately cool the planet.[58] Potential delivery vehicles for stratospheric sulphur dioxide injection include aircraft, artillery shells, stratospheric balloons and hoses suspended from towers.[59]

The genesis of this approach was a suggestion made in 1974 by Russian climatologist Mikhail Budyko that potentially dangerous climate change could be countered by deploying airplanes to burn sulphur in the atmosphere, producing aerosols to reflect sunlight away.[60] A number of recent studies have indicated that SAI could be an effective mechanism to ameliorate projected rises in temperature. A. V. Eliseev and others concluded that the amount of sulphur emissions required to compensate for projected warming by 2050 would be between five and 16 TgS/yr, increasing to between 10 and 30 TgS/yr by the end of the century.[61] Other studies have concluded that considerably smaller injections could achieve the same objective.[62] Proponents have also touted SAI for its allegedly low cost. It has been estimated that injecting enough aerosols into the stratosphere to counter even high-emission scenarios would cost only US$1 billion annually, or less than $0.01 per year to compensate for each ton of carbon dioxide emissions.[63]

There is also empirical evidence to support the potential viability of this approach. Sulfate aerosols are an important component of the troposphere and stratosphere and can substantially reduce the incoming solar radiation reaching the earth's system during powerful volcanic eruptions.[64] For example, the Mount Pinatubo eruption in 1991 spewed out approximately 20 teragrams of sulfur dioxide into the stratosphere,[65] reflecting enough sunlight back to space to cool the earth by 0.5ºC for a year following the eruption.[66]

Marine Cloud Brightening

Low-level marine stratiform clouds cover approximately one-quarter of the oceanic surface and possess albedos of 0.3 to 0.7, thus exerting a substantial cooling effect on the earth's radiative balance.[67] Cloud albedo enhancement geoengineering schemes contemplate dispersing seawater

55 Takanobu Kosugi, "Fail-Safe Solar Radiation Management Geoengineering" (2013) 18 Mitigation Adaptation Strategies for Global Change 1141 at 1142; Albert C Lin, "Balancing the Risks: Managing Technology and Dangerous Climate Change" (2009) 8(3) Issues in Leg Scholarship, art 2 at 4.

56 "Albedo is the fraction of incident sunlight that is reflected." Albedo is measured on a 0–1 scale. If a surface absorbs all incoming sunlight, its albedo is 0; if it is perfectly reflecting, its albedo is 1. Arctic Coastal Ice Processes, *Albedo,* online: <www.arcticice.org/albedo.htm>.

57 Philip Rasch, Written Testimony, US House Committee on Science and Technology Hearing, "Geoengineering IIe: The Scientific Basis and Engineering Challenges", 4 February 2010, at 5, online: <https://www.gpo.gov/fdsys/pkg/CHRG-111hhrg53007/pdf/CHRG-111hhrg53007.pdf>. There have also been suggestions of injecting pre-formed particles of other chemicals, e.g., titanium oxide, to effectuate more control over the process. Peter J Irvine et al, "An Overview of the Earth System Science of Solar Geoengineering" (2016) WIREs Climate Change at 7, DOI: <10.1002/2cc.423>.

58 J Hansen et al, "Earth's Energy Imbalance and Implications" (2011) 11 Atmospheric Chemistry Physics 13421 at 13438.

59 Alan Robock et al, "Benefits, Risks and Costs of Stratospheric Geoengineering" (2009) 36 Geophysical Research Letters L19703 at 4–7.

60 MI Budyko, *Climatic Changes*, translated by *Izmeniia Klimata* (Washington, DC: American Geophysical Union, 1977). "Sulfur in the stratosphere oxidizes via the reaction with the hydroxyl radical to sulfuric acid.... The sulfuric acid gas forms together with water vapor sulfate particles.... In the presence of aerosols sulfuric acid gas may condense onto pre-existing aerosol particles." J Feichter & T Leisner, "Climate Engineering: A Critical Review of Approaches to Modify the Global Energy Balance" (2009) 176 Eur Physical J 81 at 86.

61 AV Eliseev, II Mokhov & AA Karpenko, "Global Warming Mitigation by Means of Controlled Aerosol Emissions into the Stratosphere: Global and Regional Peculiarities of Temperature Response as Estimated in IAP RAS CM Simulations" (2009) 22(4) Atmospheric Oceanic Optics 388 at 390. 1Tg = 10^{12} grams, or 1 million metric tons. Simone Tilmes, Rolf Müller & Ross Salawitch, "The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes" (2008) 320 Science 1201 at 1202.

62 Philip J Rasch, Paul J Crutzen & Danielle B Coleman, "Exploring the Geoengineering of Climate Using Stratospheric Sulfate Aerosols: The Role of Particle Size" (2008) 35 Geophysical Research Letters L02809 at 3. "Injection of 1 Tg S/yr as small particles...reduces the warming equatorward of 40 degrees to <1K…." See also Paul J Crutzen, "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" (2006) 77 Climatic Change 211 at 213. Stratospheric loading of 1-2 Tg S/yr required; Tom ML Wigley, "Low-Intensity Geoengineering Should be Seriously Considered" (21 May 2008) Bull Atomic Scientists, online: www.thebulletin.org/web-edition/roundtables/has-the-time-come-geoengineering. Peak load of 5 TgS/yr required between 2050 and 2060, declining back to zero by 2090.

63 Jason Blackstock, "Researchers Can't Regulate Climate Engineering Alone" (2012) 486 Nature 159 at 159.

64 Rasch et al, *supra* note 24 at 4010.

65 Ben Kravitz, "Climate Engineering with Stratospheric Aerosols and Associated Engineering Parameters" (2012) National Academy of Engineering at 29, online: <https://www.nap.edu/read/18185/chapter/7>.

66 Richard A Kerr, "Pollute the Planet for Climate's Sake?" (2008) 315 Science 401 at 401.

67 John Latham et al, "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds" (2008) 366 Philosophical Transactions Royal Soc'y 3969 at 3970.

droplets approximately one micrometre in size in marine stratiform clouds. These droplets would be sufficiently large to act as cloud condensation nuclei[68] when they rise into the bases of stratiform clouds and shrink through evaporation to about half their original size.[69] Increases in cloud condensation nuclei increase cloud droplet numbers and decrease cloud droplet size.[70] This enhances overall droplet surface area and results in an increase in cloud albedo.[71] Moreover, it can extend the longevity of clouds, increasing the time-mean albedo of a region.[72]

Studies indicate that a 50 percent to 100 percent increase in droplet concentration of all marine stratiform clouds by mechanical generation of sea salt spray could increase top-of-cloud albedo by 0.02 (approximately 10 percent), which could offset warming associated with a doubling of atmospheric carbon dioxide.[73] However, there are substantial uncertainties associated with this approach, including whether increasing cloud condensation nuclei might ultimate result in evaporation that disrupts cloud albedo.[74] Moreover, the requisite top-of-cloud albedo to offset the warming associated with a doubling of carbon dioxide levels from pre-industrial levels would be markedly greater than estimated in previous studies.[75]

Stephen Salter and others have proposed the development of a fleet of approximately 1,500 remotely controlled spray vessels, drawing upon the motion from the vessels to drive underwater propellers to generate the energy for spray production.[76] As is the case with sulphur dioxide injection schemes, the cost of this approach could be extremely low, perhaps no more than $9 billion.[77]

Space-based Systems

Space-based methods seek to reduce the amount of solar radiation reaching the earth by positioning sunshields in space to reflect or deflect radiation. As is true with several other SRM options, it may be possible to reduce solar radiation inflows by 1.8 percent, potentially offsetting greenhouse effects associated with a doubling of atmospheric carbon dioxide concentrations.[78] Proposed options include placing reflectors in near-earth orbits, including the placement of 55,000 mirrors in random orbits or the creation of a ring of dust particles guided by satellites at altitudes of approximately 1,200 to 2,400 miles.[79] An alternative approach could be to establish a "cloud of spacecraft" with reflectors in a stationary orbit near the Inner Lagrange point (L1),[80] a gravitationally stable point between earth and the sun.[81] Proponents argue that this approach would ensure the stability of sunshades, whereas shields positioned in near-orbit could be pushed out of orbit by sunlight.[82]

Deployment of space-based systems could prove to be challenging, however. Some configurations of sunshades could prove to be unstable and, thus, ultimately sail out of orbit.[83] Low earth orbit systems could also face tracking problems, posing the threat that mirrors could

68 "Cloud condensation nuclei are a subset of the atmospheric aerosol population, which undergo rapid growth into cloud droplets at a specified supersaturation." Gregory C Roberts et al, "Cloud Condensation Nuclei in the Amazon Basin: 'Marine' Conditions Over a Continent?" (2001) 28:14 Geophysical Research Letters 2807 at 2807.

69 Keith Bower et al, "Computations Assessment of a Proposed Technique for Global Warming Mitigation via Albedo-Enhancement of Marine Stratocumulus Clouds" (2006) 82:1-2 Atmospheric Research 328 at 329.

70 RD Borys, DH Lowenthal & MA Wetzel, "Chemical and Microphysical Properties of Marine Stratiform Cloud" (1998) 103 J Geophysical Research: Atmospheres No. D17 at 22,073; Alan Robock et al, "Studying Geoengineering with Natural and Anthropogenic Analogs" (2013) 121 Climatic Change 445 at 452.

71 Bower et al, *supra* note 69 at 329.

72 Andy Jones, John Latham & Michael H Smith, "Radiative Forcing Due to Modification of Marine Stratocumulus Clouds" National Center for Atmospheric Research at 1, online: www.mmm.ucar.edu/people/latham/files/cloud_albedo_gcm_modelling_paper.pdf.

73 Lenton & Vaughan, *supra* note 35 at 5548; Philip Rasch, C-C (Jack) Chen & John Latham, "Global Temperature Stabilisation via Cloud Albedo Enhancement: Geoengineering Options to Respond to Climate Change" Response to National Academy Call, online: <americasclimatechoices.org/Geoengineering_Input/attachments/Latham%20National%20Academy%20Geoengineering%20090615.pdf>.

74 Oliver Morton, "Great White Hope" (2009) 458 Nature 1097 at 1099.

75 Lenton & Vaughan, *supra* note 35 at 5548.

76 Stephen Salter, Graham Sortino & John Latham, "Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming" (2008) 366 Philosophical Transactions Royal Soc'y 3989 at 3994, 4004.

77 Morton, *supra* note 74.

78 Takanobu Kosugi, "Role of Sunshades in Space as a Climate Control Option" (2010) 67 Acta Astronautica 241 at 242.

79 The Royal Society, *supra* note 12 at 32.

80 Roger Angel, "Feasibility of Cooling the Earth with a Cloud of Small Spacecraft Near the Inner Lagrange Point (L1)" (2006) 103:46 Proceedings Nat'l Acad Sci 17184 at 17184.

81 Katharine Ricke et al, "Unilateral Engineering", Non-technical Briefing Notes for a Workshop at the Council on Foreign Relations Washington DC, 5 May 2008 at 6, online: <d1027732.mydomainwebhost.com/articles/articles/cfr_geoengineering.pdf>. The Lagrange L1 point is about 900,000 miles from the earth. The Royal Society, *supra* note 12 at 32. The plan, developed by Roger Angel at the University of Arizona, contemplates the production of approximately 15 trillion silicon discs about 60-70 centimeters across; the discs would be studded with holes that could scatter incoming light. David L Chandler, "Global Shades" (21 July 2007) *New Science* at 44.

82 David W Keith, "Geoengineering the Climate: History and Prospect" (2000) 25 Annual Rev Energy & Environment 245 at 263.

83 *Ibid.*

collide.[84] The cost of deployment would also be extremely high, pegged at approximately $5 trillion by one major proponent,[85] with some commentators projecting the cost to be potentially much higher.[86] Given the existence of cheaper and less logistically challenging SRM options, "sunshade" approaches are not likely to be launched any time soon.[87]

CDR APPROACHES

CDR options seek to remove and sequester carbon dioxide from the atmosphere, either by enhancing natural biological sinks for carbon or by deploying chemical engineering to remove carbon dioxide from the atmosphere.[88] This, in turn, can increase the amount of long-wave radiation emitted by the earth back to space, reducing radiative forcing and thus exerting a cooling effect.[89]

In contrast to SRM options, which can begin to affect temperatures very rapidly,[90] CDR approaches would likely have to be deployed on a large scale for at least a century to substantially reduce atmospheric concentrations of carbon dioxide.[91] However, also in contrast to SRM options, CDR technologies address the proximal cause of warming[92] and could restore carbon dioxide to pre-industrial levels within a few centuries.[93] In the following sections, the most frequently discussed CDR options will be discussed.

84 B Govindasamy, K Caldeira & PB Duffy, "Geoengineering Earth's Radiation Balance to Mitigate Climate Change from a Quadrupling of CO_2" (2003) 37 Global & Planetary Change 157 at 167.

85 Angel, *supra* note 80 at 17,189.

86 Eric Bickel & Lee Lane, "An Analysis of Climate Engineering as a Response to Climate Change", Copenhagen Consensus Center (2009) at 48, online: <fixtheclimate.com/fileadmin/templates/page/scripts/downloadpdf.php?file=/uploads/tx_templavoila/AP_Climate_Engineering_Bickel_Lane_v.5.0.pdf>.

87 Daniel J Lunt, "Sunshades for Solar Radiation" in Tim Lenton & Naomi Vaughan, eds, *Geoengineering Responses to Climate Change* (New York, NY: Springer, 2013) 19.

88 Timothy Lenton, "The Global Potential for Carbon Dioxide Removal" (2014) in RM Harrison & RE Hester, eds, *Geoengineering of the Climate System* (Washington, DC: Royal Society of Chemistry, 2014) 53.

89 Lenton & Vaughan, *supra* note 35 at 5540.

90 The Royal Society, *supra* note 12 at 34. SRM methods could begin returning temperatures back to pre-indusrial conditions "within a few years of deployment".

91 P Ciasis et al, "Carbon and other Biogeochemical Cycles, in Climate Change 2013: The Physical Science Basis Contribution of Working Group I to the First Assessment Report of the Intergovernmental Panel on Climate Change" (2013) at 546, online: <www.ipcc.ch/report/ar5/wg1/>.

92 Sabine Mathesius et al, "Long-Term Response of Oceans to CO_2 Removal from the Atmosphere" (2015) 5 Nature Climate Change 1117 at 1117 (2015).

93 Lenton & Vaughan, *supra* note 35 at 5556.

Ocean Iron Fertilization

In a process known as "the biological pump," the production of organic matter by phytoplankton in the world's oceans results in the absorption of carbon dioxide from the atmosphere to facilitate photosynthesis, thus lowering concentrations.[94] While phytoplankton account for less than one percent of photosynthetic biomass, they are responsible for approximately half of the carbon fixation on earth.[95] A proportion of particulate organic carbon from phytoplankton sinks into the deeper ocean (below 200 m) before it decays, and can remain at these depths, thus sequestering carbon dioxide from the atmosphere, for hundreds of years.[96]

Phytoplankton production, in turn, is dependent on a variety of nutrients, including macronutrients, such as nitrogen and phosphate, and micronutrients, such as iron and zinc.[97] Proponents of an option known as ocean iron fertilization argue that phytoplankton production is limited due to low concentrations of iron in the southern ocean, subarctic Pacific and eastern equatorial Pacific waters.[98] They argue that adding iron artificially in these regions could stimulate phytoplankton production, thus enhancing carbon dioxide uptake.[99]

Several studies in the past few decades have indicated that ocean iron fertilization could reduce atmospheric carbon dioxide levels substantially, perhaps by 10 percent or

94 RS Lampitt et al, "Ocean Fertilization: A Potential Means of Geoengineering?" (2008) 366 Philosophical Transactions Royal Soc'y 3919 at 3920.

95 Sallie W Chisholm, Paul G Falkowski & John J Cullen, "Dis-Crediting Ocean Fertilization" (2001) 294 Science 309 at 309.

96 Michelle Allsopp, David Santillo & Paul Johnston, "A Scientific Critique of Ocean Iron Fertilization as a Climate Change Mitigation Strategy" (September 2007) Greenpeace Research Labs Technical Note 07/2007 at 5, online: <www.climos.com/imo/Other/Other_greenpeace_iron_fert_critiq_Sep2007.pdf>.

97 Kenneth R Arrigo, "Marine Microorganisms and Global Nutrient Cycles" (2005) 437 Nature 349 at 355.

98 Sanjay K Singh et al, "Response of Bacterioplankton to Iron Fertilization of the Southern Ocean, Antarctica" (2015) Frontiers in Microbiology 1 at 2, DOI: <10.3389/fmicb.2015.00863>, online: <dx.doi.org/10.3389/fmicb.2015.00863>; Victor Smetacek et al, "Deep Carbon Export from a Southern Ocean Iron-Fertilized Diatom Bloom" (2012) 487 Nature 313 at 313. Such areas comprise approximately 20 percent of the surface ocean; Long Cao & Ken Caldeira, "Can Ocean Iron Fertilization Mitigate Ocean Acidification?" (2010) 99 Climatic Change 303 at 304.

99 Matthew Hubbard, "Barometer Rising: The Cartagena Protocol on Biosafety as a Model for Holistic International Regulation of Ocean Fertilization Projects and Other Forms of Geoengineering" (2016) 40 Wm & Mary Envtl L & Pol'y Rev 591 at 598; Christine Bertram, "Ocean Iron Fertilization in the Context of the Kyoto Protocol and the Post-Kyoto Process" (2010), 8 Energy Pol'y 1130 at 1130.

more.[100] However, a number of more recent studies, largely reflecting field research on ocean iron fertilization, have questioned these findings. The IPCC, in its most recent assessment report, has concluded that the drawdown of atmospheric carbon dioxide with ocean iron fertilization could be as low as 15 to 30 parts per million, even under idealized conditions.[101] Moreover, the Secretariat of the Convention on Biological Diversity, in its synthesis report on geoengineering, concluded that ocean iron fertilization could only exert a "minor impact" on atmospheric concentrations of carbon dioxide.[102]

Bioenergy with Carbon Capture and Storage

Bioenergy with carbon capture and storage (BECCS) is a process by which biomass is converted to heat, electricity or liquid or gas fuels, coupled with carbon capture and sequestration (CCS). Bioenergy feedstocks include the following:

- energy derived from woody biomass harvested from forests, including fuel wood, charcoal and residues;
- energy crops, such as jatropha and palm;
- food crops, including corn, sweet sorghum and annual crops, such as switchgrass; and
- agro-residues (animal manure and crop residues), agro-industrial and municipal solid wastes and other biological resources.[103]

In the context of power production facilities, the CCS process involves capturing carbon dioxide from flue gases in the post-combustion phase or modifying the combustion process to generate pure or high-concentration streams of carbon dioxide.[104] BECCS technologies could capture 90 percent or more of the carbon dioxide released through biomass production.[105]

After capture, carbon dioxide is compressed and transported to a site for storage, either underground or in the oceans.[106] There are also proposals for using carbon dioxide for other purposes, such as enhanced oil recovery and biochemical conversion into biofuels or for energy storage technologies.[107]

BECCS is one of a group of carbon dioxide removal options characterized as "negative emissions technologies" (NETs) because these approaches are capable of removing GHGs from the atmosphere, capturing carbon dioxide at the source or engineering enhancement of natural carbon sinks.[108] BECCS effectuates this by the absorption of carbon dioxide through the growth cycle of biomass feedstocks and the capture of the carbon dioxide produced during the combustion of biomass energy.[109] The vast majority of

100 V Melissa Eick, "A Navigational System for Uncharted Waters: The London Convention and London Protocol's Assessment Framework on Ocean Iron Fertilization" (2010) 46 Tulsa L Rev 351 at 357; Victor Smetacek & SWA Maqvi, "The Next Generation of Iron Fertilization Experiments in the Southern Ocean" (2008) 366 Philosophical Transactions Royal Soc'y 3947 at 3956; F Joos, JL Sarmiento & U Siegenthaler, "Estimates of the Effect of Southern Ocean Fertilization on Atmospheric CO_2 Concentrations" (2001) 349 Nature 772 at 773.

101 Ciasis et al, *supra* note 91 at 551.

102 Secretariat of the Convention on Biological Diversity, "Scientific Synthesis of the Impacts of Ocean Fertilization on Marine Biodiversity" (2009) CBD Technical Series No 45 at 22, online: <www.cbd.int/doc/publications/cbd-ts-45-en.pdf>. See also US Government Accountability Office, Center for Science, Technology and Engineering, "Climate Engineering" Technology Assessment (July 2011) at 29, online: <www.gao.gov/new.items/d1171.pdf>.

103 Alisher Mirzabaev et al, "Bioenergy, Food Security and Poverty Reduction" (July 2014) Center for Development Research, University of Bonn, Working Paper No 135 at 11; Venkatesh Balan, "Current Challenges in Commercially Producing Biofuels from Lignocellulosic Biomass" (2014) 12 Intl Scholarly Research Notices: Biotechnology 1 at 4–5; Ayhan Demirbas, "Bioenergy, Global Warming, and Environmental Impacts" (2010) 26 Energy Sources 225 at 226.

104 Steve Rackley, *Carbon Capture and Storage* (Amsterdam: Elsevier, 2009) at 21.

105 Joris Kornneeff et al, "Global Potential for Biomass and Carbon Dioxide Capture, Transport and Storage up to 2050" (2012) 11 Intl J Greenhouse Gas Control 117 at 118.

106 US Environmental Protection Agency, "Carbon Dioxide Capture and Sequestration", online: <www3.epa.gov/climatechange/ccs/#CO2Capture>; Intergovernmental Panel on Climate Change, (2005) "Special Report: Carbon Dioxide Capture and Storage" 195–307, online: <digital.library.unt.edu/ark:/67531/metadc12051/m2/1/high_res_d/srccs_wholereport.pdf>. Terrestrial storage options include depleted reservoirs for oil and gas and deep saline aquifers: Ben Caldecott, Guy Lomax & Mark Workman, "Stranded Carbon Assets and Negative Emissions Technologies" (February 2015) Smith School of Enterprise and the Environment, University of Oxford, Working Paper at 18, online: <www.smithschool.ox.ac.uk/research-programmes/stranded-assets/Stranded%20Carbon%20Assets%20and%20NETs%20-%2006.02.15.pdf>.

107 Rowan Oloman, "Carbon Recycling: An Alternative to Carbon Capture and Storage" (August 2009) 236:8 Pipeline & Gas J, online: <pgjonline.com/2009/08/06/carbon-recycling-an-alternative-to-carbon-capture-and-storage/>; Alexandra B Klass & Elizabeth J Wilson, "Carbon Capture and Sequestration: Identifying and Managing Risks" (2009) 8:3 Art 1 Issues in Leg Scholarship 1 at 6, online: <scholarship.law.umn.edu/cgi/viewcontent.cgi?article=1037&context=faculty_articles>; Peter Maloney, "General Electric Seeks to Capture CO_2 for Storage, Utility Dive", 12 March 2016, online: <www.utilitydive.com/news/general-electric-seeks-to-capture-co2-for-energy-storage/415514/>.

108 T Gasser et al, "Negative Emissions Physically Needed to Keep Global Warming Below 2°C" (2015) 6 Nature Communications Art No 7958 at 2; UK Parliament, Parliamentary Office of Science & Technology, "Negative Emissions Technologies" (October 2013) POSTnote 447 at 1, online: <researchbriefings.files.parliament.uk/documents/POST-PN-447/POST-PN-447.pdf>.

109 C Gough & NE Vaughan, "Synthesizing Existing Knowledge on the Feasibility of BECCS" (February 2015) AVOID2 at 5, online: <avoid-net-uk.cc.ic.ac.uk/wp-content/uploads/delightful-downloads/2015/07/Synthesising-existing-knowledge-on-the-feasibility-of-BECCS-AVOID-2_WPD1a_v1.pdf>.

mitigation scenarios developed in integrated assessment models, under which temperatures are kept to 2°C or below, contemplate extensive deployment of NETs during the course of this century,[110] with BECCS cited as the primary NETs option.[111] However, the actual potential of BECCS to sequester carbon is highly uncertain at this incipient stage of development.[112] One recent study projected potential sequestration of 1.5 $GtCO_2$/yr by 2050 and 5 to 16 $GtCO_2$/yr by 2100,[113] while another pegs the potential range at between 1.8 and 17.4 GtC/yr.[114] By means of comparison, global carbon dioxide emissions in 2015 were estimated to be 35.7 GtC.[115]

Direct Air Capture

Direct air capture (DAC) is a process for extracting carbon dioxide from ambient air in a closed-loop industrial process. The most widely discussed method involves drawing air through towers and bringing it into contact with a chemical solution that naturally absorbs carbon dioxide, such as sodium hydroxide, in a device called a contactor.[116] These machines could be capable of capturing 1,000 times more carbon dioxide than could a tree of comparable size.[117]

Once carbon dioxide-capturing sorbents become saturated, a regeneration process is used to release the carbon dioxide for pipeline compression and storage or re-use in other processes.[118] Captured carbon dioxide could be stored using the methods described above in terms of BECCS or for alternative purposes.[119] One clear benefit of DAC systems is that they can facilitate uptake of carbon dioxide emissions from small and hard-to-control distributed sources, such as the transportation sector, which constitute more than half of total emissions.[120] As is the case with BECCS, DAC constitutes a negative emissions technology.[121] One recent study of DAC potential in the United States alone estimated that it might be possible to sequester approximately 13 $GtCO_2$/yr, with cumulative removal of approximately 1,100 Gt up to 2100,[122] while another study estimated sequestration potential of between 3.7 and 10 $GtCO_2$/yr by 2100.[123]

While there are efforts currently to develop pilot demonstration projects, an imposing barrier to large-scale deployment of DAC may be its potential costs, with some estimates ranging from $600 to thousands of dollars per ton of captured carbon dioxide.[124] However, other researchers

110 IPCC, Fifth Assessment Report, Working Group III, Ch 6, "Assessing Transformation Pathways" at 93; Etsushi Kato & Yoshiki Yamagata, "BECCS Capability of Dedicated Bioenergy Crops under a Future Land-Use Scenario Targeting Net Negative Carbon Emissions" (2014) 2 Earth's Future 421 at 421. "Of the 400 [IPCC] scenarios that have a 50% or better chance of no more than 2°C warming…344 assume the successful and large-scale uptake of negative-emission technologies;" Kevin Anderson, "Duality in Climate Science" (2015) 8 Nature Geoscience 989 at 989 .

111 Gasser et al, *supra* note 108 at 5. See also José Roberto Moreira et al, "BECCS Potential in Brazil: Achieving Negative Emissions in Ethanol and Electricity Production Based on Sugar Cane Bagasse and Other Residues" (2016) 179 Applied Energy 55 at 56; BECCS "will play a vital role in reaching the required level of emission reductions in the future." Sabine Fuss, "Betting on Negative Emissions" (2014) 4 Nature Climate Change 850 at 850.

112 There are currently 15 pilot-scale BECCS plants globally; Gough & Vaughan, *supra* note 109 at 20. And the first large-scale BECCS plant is due to begin operation in 2016; Global CCS Institute, Illinois Industrial Carbon Capture and Storage Project, online: <www.globalccsinstitute.com/projects/illinois-industrial-carbon-capture-and-storage-project>.

113 Caldecott, Lomax & Workman, *supra* note 106 at 19, 22.

114 Andrew Wiltshire & T Davies-Barnard, "Planetary Limits to BECCS Negative Emissions" (March 2015) AVOID2 at 15, online: <avoid-net-uk.cc.ic.ac.uk/wp-content/uploads/delightful-downloads/2015/07/Planetary-limits-to-BECCS-negative-emissions-AVOID-2_WPD2a_v1.1.pdf>.

115 Robert B Jackson, "Reaching Peak Emissions" (January 2016) 6 Nature Climate Change 7 at 7.

116 Robert Socolow et al, "Direct Air Capture of CO_2 with Chemicals" (2011) American Physical Society at 7–9, online: <https://www.aps.org/policy/reports/assessments/upload/dac2011.pdf>. Other potential capture methods include mineral capture by water of crystallization or hydroxyl cation cycles; R Stuart Haszeldine, "Can CCS and NET Enable the Continued Use of Fossil Carbon Fuels after CoP21?" (2016) 32:2 Oxford Rev Econ Pol'y 304 at 310.

117 Marianne Lavelle, "Out of Thin Air: The Quest to Capture Carbon Dioxide" (12 August 2011) *National Geographic*, online: <news.nationalgeographic.com/news/energy/2011/08/110811-quest-to-capture-carbon-dioxide/>.

118 Duncan McClaren, "Capturing the Imagination: Prospects for Direct Air Capture as a Climate Measure" (25 March 2014) Geoengineering our Climate? Ethics, Politics and Governance, Case Study at 1-2, online: <geoengineeringourclimate.com/2014/03/25/capturing-the-imagination-prospects-for-direct-air-capture-as-a-climate-measure-case-study/>.

119 See *supra* note 107. See also David W Keith, Kenton Heidel & Robert Cherry, "Capturing CO_2 from the Atmosphere: Rationale and Process Design Considerations" in B Launder & M Thompson, eds, *Geo-Engineering Climate Change: Environmental Necessity or Pandora's Box* (Cambridge, UK: Cambridge University Press, 2010) 125, online: <keith.seas.harvard.edu/papers/116.Cherry.Heidel.CapCO2FromAtmosp.p.pdf>; Eli Kintisch, "Can Sucking CO_2 Out of the Atmosphere Really Work?" (7 October 2014) MIT Tech Rev, online: <www.technologyreview.com/s/531346/can-sucking-co2-out-of-the-atmosphere-really-work/>.

120 Manya Ranjan & Howard J Herzog, "Feasibility of Air Capture" (2011) 4 Energy Procedia 2869 at 2870; David Keith, "Why Capture CO_2 from the Atmosphere?" (2009) 325 Science 1654 at 1655.

121 Caldecott, Lomax & Workman, *supra* note 106 at 7.

122 *Climate Intervention: Reflecting Sunlight to Cool Earth*, *supra* note 30 at 75.

123 Caldecott, Lomax & Workman, *supra* note 106 at 22.

124 Socolow et al, *supra* note 116 at i; Ranjan & Herzog, *supra* note 120 at 2875.

have contended that the costs could be much lower.[125] Other challenges would include finding suitable sites for carbon dioxide sequestration, as well as safety, public perception and sequestration reliability questions.[126]

Potential Risks Associated with Climate Geoengineering

SRM OPTIONS

Potential Precipitation Impacts

SAI geoengineering could adversely impact the globe's hydrological cycle. SAI could abate increases in surface temperatures by reducing incoming solar radiation. However, continued simultaneous absorption of long-wave radiation by rising levels of atmospheric carbon dioxide could increase the vertical stability of atmosphere. This could, in turn, suppress convective activities and, most importantly, precipitation.[127] Additionally, infrared absorption by the introduction of sulphur aerosols into the stratosphere could decrease the downward emission of infrared radiation into the troposphere, further reducing precipitation.[128]

While the deployment of SAI geoengineering could result in a decline in mean global precipitation, its impacts could be far more severe in the global south.[129] H. Schmidt and others projected that deployment could reduce precipitation by 20 percent in the southern branch of the inter-tropic convergence zone,[130] with U. Niemeier reaching similar findings.[131] Reductions of this magnitude could modify the Asian and African monsoons, "impacting the food supply to billions of people"[132] and visiting "humanitarian disasters" upon such regions.[133] The South Asian summer monsoon provides up to 80 percent of annual mean precipitation in India, sustaining the country's agriculture, health and water needs.[134] In Africa, production of important crops such as maize are critically linked to the timing and duration of precipitation.[135] Recent research indicates that deployment of SAI in the northern hemisphere could trigger droughts in the Sahel, potentially reducing net primary productivity by 60 to 100 percent.[136] There is also empirical support for this proposition. As indicated above, when Mount Pinatubo erupted in 1991, it released approximately 20 teragrams into the stratosphere.[137] This is the mid-range estimate of the amount of sulphur dioxide that might have to be injected into the stratosphere by the end of the century to compensate for twenty-first century warming.[138] In the year following the eruption, the earth experienced the least amount of rainfall on record, more than 50 percent lower than in any previous year,[139] as well as a record decrease in runoff and discharge into the ocean.[140]

However, one must be cautious about potential precipitation impacts of SRM options, and substantial

125 Xiaoyang Shi, "Capture CO_2 from Ambient Air Using Nanoconfined Iron Hydration" (2016) 128 Angewandte Chemie 4094 to 97; Chen & Massimo Tavoni, "Direct Air Capture of CO_2 and Climate Stabilization: A Model Based Assessment" (2013) 118 Climatic Change 59 at 60; Geoffrey Holmes & David W Keith, "An Air-Liquid Contractor for Large-Scale Capture of CO_2 from Air" (2012) 370 Philosophical Transactions Royal Soc'y A 4380–4403.

126 *Climate Intervention: Reflecting Sunlight to Cool Earth, supra* note 30 at 75.

127 Cao Long, Gao Chao-Chao & Zhao Li-Yun, "Geoengineering: Basic Science and Ongoing Research Efforts" (2015) 6 Advances in Climate Change Research 188 at 190; Alan Robock, "Stratospheric Aerosol Geoengineering" (2015) AIP Conference Proceedings 1652 at 190.

128 Angus J Ferraro & Hannah G Griffiths, "Quantifying the temperature-independent effect of stratospheric aerosol geoengineering on global-mean precipitation in a multi-model ensemble" (2016) 11 Envtl Research Letters 1 at 16 (2016), online: <iopscience.iop.org/article/10.1088/1748-9326/11/3/034012/pdf>.

129 H Damon Matthews & Ken Caldeira, "Transient Climate-Carbon Simulations of Planetary Geoengineering" (2007) 104 Proceedings Natl Acad Sci 9949 at 9951.

130 H Schmidt et al, "Solar Irradiance Reduction to Counteract Radiative Forcing from a Quadrupling of CO_2: Climate Responses Simulated by Four Earth System Models" (2012) 3 Earth Systems Dynamics 63 at 72.

131 U Niemeier, "Solar Irradiance Reduction via Climate Engineering: Impact of Different Techniques on the Energy Balance and the Hydrological Cycle" (2013) 118 J Geophysical Research: Atmospheres 11,095 at 11,915.

132 The Royal Society, *supra* note 12 at 31.

133 Holly Jean Buck, "Geoengineering: Re-Making Climate for Profit or Humanitarian Intervention?" (2011) 43:1 Development & Change 253 at 255.

134 Massimo A Bollasina, Yi Ming & V Ramaswamy, "Anthropogenic Aerosols and the Weakening of the South Asian Summer Monsoon" (2011) 334 Science 502 at 502.

135 Pablo Suarez, "Geoengineering and the Humanitarian Challenge: What Role for the Most Vulnerable?" (13 August 2013) Geoengineering our Climate, Opinion Article at 3, online: <https://geoengineeringourclimate.files.wordpress.com/2013/08/suarez-et-al-2013-ge-and-the-humanitarian-challenge-click-for-download.pdf>.

136 Jim M Haywood et al, "Asymmetric Forcing from Stratospheric Aerosols Impacts Sahelian Rainfall" (2013) 3 Nature Climate Change 660 at 663.

137 Kravitz, *supra* note 65.

138 Eliseev, Mokhov & Karpenko, *supra* note 61 at 390.

139 Kevin Bullis, "The Geoengineering Gambit" (21 December 2009) MIT Technology Rev, online: <www.technologyreview.com/s/416801/the-geoengineering-gambit/>. See also Gabriele C Hegerl & Susan Solomon, "Risks of Climate Engineering" (2009) 325 Science 955 at 955.

140 G Bala, PB Duffy & KE Taylor, "Impact of Geoengineering Schemes on the Global Hydrological Cycle" (2008) 105:22 Proceedings Natl Acad Sci 7664 at 7664.

additional research would clearly be needed if such options were to be considered.[141] As Simon Tilmes and others observe, "different models and scenarios do not always agree in the sign of the change of monsoonal precipitation in response to geoengineering."[142] Moreover, some researchers contend that temperature reductions associated with SRM deployment would also decrease evaporation, increasing soil moisture and potentially offsetting any possible loss in food production.[143]

Marine cloud brightening geoengineering options also pose dangers in this context. One recent study indicated that deployment could reduce precipitation by 50 percent in some areas of South America, with a corresponding decline in net primary productivity by as much as 50 to 100 percent.[144] The impact of space-based systems on precipitation remains unclear,[145] but several researchers have expressed fear about potential adverse impacts on regional precipitation, especially in the tropics.[146]

Potential Impacts on the Ozone Layer

Sunlight-related skin cancer is responsible for approximately 60,000 human deaths annually, as well as hundreds of thousands of new cases and billions of dollars in direct economic losses.[147] The diminution of the ozone layer over the past few decades, which is primarily attributable to anthropogenic ozone-depleting substances, is a major contributor to these impacts.[148] Fortunately, the establishment of the Montreal Protocol, with its scheduled phaseout of most ozone-depleting substances, has been projected to reduce the number of skin cancer cases by 14 percent annually by 2030, translating into two million cases. Moreover, these numbers are anticipated to "grow dramatically" thereafter.[149]

Deployment of SAI geoengineering options, however, could radically change this equation. Injection of sulphur dioxide particles into the stratosphere would substantially increase the available surface areas for heterogeneous reactions in which inactive forms of chlorine and bromine could be converted to forms that could facilitate catalytic destruction of ozone.[150] Thus, while current international policies could facilitate a return of stratospheric ozone levels to their original states by 2050,[151] large-scale deployment of SAI geoengineering options could delay recovery of the ozone layer for 30 to 70 years or more.[152] Moreover, the projected loss of ozone would be "remarkable," perhaps reaching levels higher than the peak of depletion by ozone-depleting substances in the last century.[153] In some winters, the loss of ozone would be comparable to the total amount of ozone available in the lower portions of the stratosphere

141 CJ Gabriel & A Robock, "Stratospheric Geoengineering Impacts on El Niňo/Southern Oscillation" (2015) 15 Atmospheric Chemistry & Physics Discussions 9173 at 9187.

142 Simon Tilmes et al, "The Hydrological Impact of Geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP)" (2013) 118 J Geophysical Research: Atmospheres 11,036 at 11,037.

143 DJ Lunt et al, "'Sunshade World:' A Fully Coupled GCM Evaluation of the Climate Impacts of Geoengineering" (2008) 35 Geophysical Research Letters 1 at 4.

144 Andy Jones, Jim Haywood & Olivier Boucher, Climate Impacts of Geoengineering Marine Stratocumulus Clouds (2009) 114 J Geophysical Research 1 at 5, D10106.

145 The Royal Society, *supra* note 12 at 33.

146 Lunt et al, *supra* note 143 at 4; U.S. House of Representatives, Committee on Science and Technology, 111th Cong, *Engineering the Climate: Research Needs and Strategies for International Coordination* (2010) Serial No. 111-A at 42. Lunt et al contend that regional declines in precipitation in a "sunshade world" would not, however, likely adversely crop production because lowered surface temperatures would lead to a decline in temperatures and a small increase in soil moisture.

147 Ken Caldeira & Lowell Wood, "Global and Arctic Climate Engineering: Numerical Model Studies" (2009) 366 Philosophical Transactions Royal Soc'y A 4039 at 4050.

148 Center for International Earth Science Information Network, The Relationship of Skin Cancer Prevalence and the Increase in Ultraviolet-B Exposure Due to Ozone Depletion, online: <www.ciesin.org/TG/HH/ozskin1.html>; WJM Martens et al, "The Impact of Ozone Depletion on Skin Cancer Incidence: An Assessment of the Netherlands and Australia" (1996) 1 Envtl Modeling & Assessment 229–40.

149 Arjan van Dijk et al, "Skin Cancer Risks Avoided by the Montreal Protocol—Worldwide Modelling Integrating Coupled Climate-Chemistry Models with a Risk Model for UV" (2013) 89 Photochemistry & Photobiology 234 at 234. See also MP Chipperfield et al, "Quantifying the Ozone and Ultraviolet Benefits of Already Achieved by the Montreal Protocol" (2014) 6 Nature Communications 1 at 8, DOI: <10.1038/ncomms8233>.

150 DK Weisenstein, DW Keith & JA Dykema, "Solar Geoengineering Using Solid Aerosol in the Stratosphere" (2015), 15 Atmospheric Chemistry & Physics 11835 at 11846; FD Pope et al, "Stratospheric Aerosol Particles and Solar-Radiation Management" (2012) 2 Nature Climate Change 713 at 715.

151 UNEP, Ozone Secretariat, *Synthesis of the 2014 Reports of the Scientific, Environmental Effects, and Technology & Economic Assessment Panels of the Montreal Protocol* (2014) at 5, online: <ozone.unep.org/Assessment_Panels/SynthesisReport2014.pdf>.

152 Simone Tilmes, Rolf Müller & Ross Salawitch, "The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes" (2008) 320 Science 1201 at 1204.

153 P Heckendorn et al, "The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone" (2009) 4 Envtl Research Letters 1 at 7.

above the Arctic, with drastic declines over the Antarctic as well.[154]

The Threat of a Termination Effect

The "termination effect" refers to the potential for a huge multi-decadal pulse of warming, should the use of a deployed SRM scheme be terminated abruptly due to technological failure, a pandemic, war or a decision by future policy makers that its negative impacts compelled them to do so.[155] This would be a consequence of the buildup of carbon dioxide that had accrued in the atmosphere in the interim, with its suppressed warming effect, as well as the temporary suppression of climate-carbon feedbacks.[156]

The ramifications of the termination effect could be "catastrophic."[157] As one study recently concluded, "[S]hould the engineered system later fail for technical or policy reasons, the downside is dramatic.... The climate suppression has only been temporary, and the now CO_2-loaded atmosphere quickly bites back, leading to severe and rapid climate change with rates up to 20 times the current rate of warming of approximately 0.2ºC per decade."[158]

As a consequence, temperatures could increase 6ºC to 10ºC in the winter in the Arctic region *within 30 years of termination of the use of SRM technology*, with northern land masses seeing increases of 6ºC in the summer.[159] Moreover, temperatures could jump 7ºC in the tropics in 30 years.[160] Projected temperature increases after termination would occur more rapidly than during one of the most extreme and abrupt global warming events in history, the Paleocene-Eocene Thermal Maximum.[161] It is beyond contention that climatic changes of this magnitude "could trigger unimaginable ecological effects."[162] To put this rate of temperature increase in perspective, even a warming rate of greater than 0.1ºC per decade could threaten most major ecosystems and decrease their ability to adapt.[163] Should temperatures increase at a rate of 0.3ºC per decade, only 30 percent of all impacted ecosystems and only 17 percent of all impacted forests would be able to adapt.[164] Moreover, temperature increases of this magnitude and rapidity would imperil many human institutions.[165] It is also likely that the termination effect would have disproportionate impacts on some of the world's poorest and most vulnerable peoples, as the greatest acceleration of warming over land would be projected to occur in lower latitudes.[166] Moreover, net primary productivity could decline in low latitude regions.[167]

CDR OPTIONS: POTENTIAL NEGATIVE IMPACTS

Ocean iron fertilization could pose several risks to ecosystems and humans who rely on ocean resources. Assuming that fertilization spurs the proliferation of phytoplankton, there is a real danger that it could result in shifts in community composition that could threaten

154 Tilmes, Müller & Salawitch, *supra* note 152 at 1203. Stratospheric ozone depletion increased in the Arctic after the eruption of Mt. Pinatubo released 20 Mt. of SO_2 into the stratosphere in 1991; Tilmes et al, *supra* note 142 at 11,037. It was estimated that the global column ozone loss after Mt. Pinatubo was 2.5 percent, while the loss after the eruption of El Chicón in 1982 was approximately 16 percent; Paul Crutzen, "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma" (2006) 77 Climatic Change 211 at 215.

155 Seth D Baum, "The Great Downside Dilemma for Risky Emerging Technologies" (2014) 89 Physica Scripta 1 at 4; Andrew Ross and H Damon Matthews, "Climate Engineering and the Risk of Rapid Climate Change" (2009) 4 Envtl Research Letters 1 at 5.

156 H Damon Matthews & Ken Caldeira, "Transient Climate-Carbon" (2007) 104:2 Proceedings Natl Acad Sci 9951.

157 B Govindasamy et al, "Impact of Geoengineering Schemes on the Terrestrial Biosphere" (2002) 29:22 Geophysical Research Letters 18-1 at 18-3.

158 Peter G Brewer, "Evaluating a Technological Fix for Climate" (2007) 104:24 Proceedings Natl Acad Sci 9915 at 9915. See also Niemeier, *supra* note 131 at 11,916; JC Moore, S Jevrejeva & A Grinstad, "Efficacy of Geoengineering to Limit 21st Century Sea-Level Rise" (2010) 107:36 Proceedings Natl Acad Sci 15,699–15,703.

159 Victor Brovkin et al, "Geoengineering Climate by Stratospheric Sulfur Injections: Earth System Vulnerability to Technological Failure" (2009) 92 Climatic Change 243 at 254.

160 Eli Kintisch, "Scientists Say Continued Warming Warrants Closer Look at Drastic Fixes" (2007) 318 Science 1054 at 1055.

161 *Ibid.*

162 *Ibid*. See also Andrew Ross & H Damon Matthews, "Climate Engineering and the Risk of Rapid Climate Change" (October-December 2009) 4 Envtl Research Letters 045103, online: <iopscience.iop.org/1748-9326/4/4/045103>. "It seems likely that two decades of very high rates of warming would be sufficient to severely stress the adaptive capacity of many species and ecosystems, especially if preceded by some period of engineered climate stability."

163 A Vliet & R Leemans, "Rapid Species' Response to Changes in Climate Require Stringent Climate Protection Targets" (2006) Avoiding Dangerous Climate Change at 135–41.

164 R Leemans & B Eickhout, "Another Reason for Concern: Regional and Global Impacts on Ecosystems for Different Levels of Climate Change" (2004) 14 Global Envtl Change: Human Pol'y Dimensions 219–228.

165 William CG Burns, "Climate Geoengineering: Solar Radiation Management and its Implications for Intergenerational Equity" (2011) 4 Stanford JL Science & Pol'y 37 at 46-9, online: <journals.law.stanford.edu/sites/default/files/stanford-journal-law-science-policy-sjlsp/print/2011/05/burns_final.pdf>; Brewer, *supra* note 158 at 9915; Kintisch, *supra* note 160 at 1055.

166 Andy Jones et al, "The Impact of Abrupt Suspension of Solar Radiation Management (Termination Effect) in Experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP)" (2013) 118 J Geophysical Research: Atmospheres 9743 at 9749.

167 *Ibid.*

the integrity of ocean ecosystems. For example, during one study, the CROZet Natural Iron Bloom and EXport Experiment (CROZEX),[168] iron fertilization resulted in the increased abundance, diameter and biomass of *Phaeocystis antarctica,* a colonizing species that proved unpalatable to mesozooplankton in the region.[169] Should this occur on a large scale in fertilized oceans, it could result in so-called "regime shifts," with associated large-scale changes in regional biogeochemistry and the structure of the food web.[170] This could include impacts on large predators, including copepods, krill, salps, jellyfish and other fish,[171] with "potentially devastating" consequences.[172] Of course, it is also possible that species higher on the food chain could ultimately benefit from fertilization,[173] but this remains far from certain.

Phytoplankton blooms can also block sunlight in deeper waters and overload bacterial decomposers that take up oxygen.[174] Thus, ocean iron fertilization strategies that stimulate phytoplankton production might produce hypoxic (low-oxygen) or anoxic (oxygen-deprived) ocean environments.[175] Hypoxic or anoxic environments can result in massive fish kills, as well as increased mortality rates for critical prey species, such as krill, which serve as the base of the southern ocean food chain.[176] Ocean iron fertilization could also generate large diatom blooms that could produce a highly potent neurotoxin, domoic acid, as well as toxic algal blooms in coastal waters that could threaten food webs.[177] Also, it could remove nutrients and stunt phytoplankton growth in other areas where this is naturally occurring, as recent model simulations from the tropical eastern Pacific suggest.[178] Finally, enhancement of oceanic uptake of carbon dioxide could substantially increase ocean acidification, including accelerating the threshold for serious impacts in the southern ocean by a few decades.[179] Ocean acidification could imperil many ocean species, including calcifying species and important commercial fish species.[180]

Large-scale deployment of BECCS could pose both socio-economic and environmental risks. One striking feature of BECCS is the potential amount of land that might be required to be diverted from other uses, including food production and livelihood-related activities, to provide bioenergy feedstocks. A recent study projected that delivery of three gigatons of carbon dioxide equivalent negative emissions annually would require a land area of approximately 380 to 700 million hectares in 2100, translating into seven to 25 percent of agricultural land and 25 to 46 percent of arable and permanent crop area.[181] The range of land demands would be two to four times larger than land areas that have been classified as abandoned or marginal.[182] This relatively modest level of emissions removal would be equivalent to a startling 21 percent of total current human appropriate net primary productivity.[183] While it might be possible to reduce these impacts by emphasizing the use of agricultural residue and waste feedstocks, this option could prove to be extremely

168 CROZEX, online: <www.annahickman.info/crozex-project.html>.

169 Lampitt et al, *supra* note 94 at 3925.

170 John J Cullen & Philip W Boyd, "Predicting and Verifying the Intended and Unintended Consequences of Large-Scale Ocean Iron Fertilization" (2008) 364 Marine Ecology Progress Series 295 at 300.

171 Randall S Abate & Andrew B Greenlee, "Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change, and the International Environmental Framework" (2010) 27 Pace Envtl L Rev 555 at 567; Kenneth L. Denman, "Climate Change, Ocean Processes and Ocean Iron Fertilization" (2008), 225 Marine Ecol Progress Series 219 at 223.

172 Rosemary Rayfuse, Mark G Lawrence & Kristina M Gjerde, "Ocean Fertilisation and Climate Change: The Need to Regulate Emerging High Seas Uses" (2008) 23 Marine & Coastal L 297 at 306. See also P Falkowski, RT Barber & V Smetacek, "Biogeochemical Controls and Feedbacks on Ocean Primary Production" (1998) 381 Science at 200–206.

173 V Smetacek & SWA Naqvi, "The Next Generation of Iron Fertilization Experiments in the Southern Ocean" (2008) 366 Philosophical Transactions Royal Soc'y A 3947 at 3962.

174 Jennie Dean, "Iron Fertilization: A Scientific Review with International Policy Recommendations" (2009) 32:2 Environs 322 at 330.

175 Christine Bertram, "Ocean Iron Fertilization in the Context of the Kyoto Protocol and the Post-Kyoto Process" (2010) 38 Energy Pol'y 1130 at 1131; Patricia M Gilbert et al, "Ocean Urea Fertilization for Carbon Credits Poses High Ecological Risks" (2008) 56 Marine Pollution Bull 1049 at 1051.

176 Cullen & Boyd, *supra* note 170 at 299; Dean, *supra* note 174 at 330.

177 Quirin Schiermeier, "Dumping Iron at Sea Does Sink Carbon" (18 July 2012) Nature, online: <www.nature.com/news/dumping-iron-at-sea-does-sink-carbon-1.11028>; Charles G Trick et al, "Iron Enrichment Stimulates Toxic Diatom Production in High-Nitrate, Low-Chlorophyll Areas" (2010) 107:13 Proceedings Natl Acad Sci 5887 at 5891.

178 X Jin et al, "The Impact of Atmospheric CO_2 of Iron Fertilization Induced Changes in the Ocean's Biological Pump" (2008) 5 Biogeosciences 390–92.

179 A Oschlies et al, "Side Effects and Accounting Aspects of Hypothetical Large-Scale Southern Ocean Iron Fertilization" (2010) 7 Biogeosciences 4017 at 4026.

180 International Institute for Applied Systems Analysis, "How Will Ocean Acidification Impact Marine Line" (3 February 2015), online: <www.iiasa.ac.at/web/home/about/news/150203-Ocean-Acid.html>; William CG Burns, "Anthropogenic Carbon Dioxide Emissions and Ocean Acidification: The Potential Impacts on Ocean Biodiversity", in Robert A Askins et al, eds, *Saving Biological Diversity* (New York: Springer, 2008) at 190–95.

181 Pete Smith et al, "Biophysical and Economic Limits to Negative CO_2 Emissions" (2016) 6 Nature Climate Change 42 at 46. See also Phil Williamson, "Scrutinize CO_2 Removal Methods" (2016) 530 Nature 153 at 154; Markus Bonsch et al, "Trade-offs Between Land and Water Requirements for Large-Scale Bioenergy Production" (2014) 8 GCB Bioenergy 11 at 11.

182 Smith et al, *supra* note 181 at 42.

183 *Ibid* at 46.

limited.[184] Reliance on so-called "second generation" lignocellulosic feedstocks that are produced from the woody part of plants, such as wheat straw and corn husks, or algal biofuels could also substantially reduce pressure on agricultural and forest lands. However, there are currently serious technical and economic constraints that severely restrict production.[185]

Demands of this magnitude on land could substantially raise food prices on basic commodities.[186] This could imperil food security for many of the world's most vulnerable, with many families in developing countries already expending 70 to 80 percent of their income on food.[187] There is empirical evidence to support this proposition in the context of efforts in the past decade to increase biofuel expansion. Biofuel expansion, in many cases at the expense of food production, was one of the major factors precipitating substantial spikes in food prices in 2007-2008 and 2012.[188] Food price increases and the reduction of food production imperiled the food security of many in Africa and in other parts of the developing world.[189] Increases in food prices in 2007 led to food riots in a number of countries and elevated the number of people living in hunger to an historical high of over one billion.[190] According to a 2008 report by Oxfam, the "scramble to supply" biofuels such as palm oil, which was partly driven by EU biofuel targets, exacerbated the food price crises, brought "30 million people into poverty" and put 60 million indigenous people at risk.[191] While it is difficult to estimate the impact of large-scale deployment of BECCS on food prices, even the far more modest goal of scaling up biofuels production could result in price increases of 15 to 40 percent.[192]

Efforts to develop feedstock for bioenergy can also result in the displacement of the poor from land, which can undermine food security, livelihoods, political power and social identity.[193] A recent report listed more than 293 reported "land grabs" for the purposes of biofuel plantation expansion, encompassing more than 17 million hectares of land.[194] Moreover, there is ample historic evidence of land seizures from vulnerable populations for other economic enterprises, including mineral extraction and industrial projects.[195] While supporters of BECCS contend that bioenergy expansion can be effectuated primarily through "marginal," "degraded" or "abandoned" land,[196] most often found in developing countries, the reality is that hundreds of millions may rely on these lands for income and

184 Caldecott, Lomax & Workman, *supra* note 106 at 16.

185 *Ibid.* Secretariat of the Convention on Biological Diversity, "Biofuels and Biodiversity" (2012) CBD Technical Series No 65 at 9, online: <https://www.cbd.int/doc/publications/cbd-ts-65-en.pdf>; Committee on the Sustainable Development of Algal Biofuels et al, "Sustainable Development of Algal Biofuels in the United States" (2012) at 157–202, online: <www.ourenergypolicy.org/wp-content/uploads/2012/10/13437.pdf>. Moreover, some studies have even suggested that lignocellulosic biofuels might require more land than first generation biofuels.

186 Scott Barrett, "Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology" (2014) 8:2 Rev Envtl Econ 249 at 254.

187 UN Office of the High Commissioner, Mandate of the Special Rapporteur on the Right to Food, *Note on the Impacts of the EU Biofuels Policy on the Right to Food*, 23 April 2013, online: <www.srfood.org/images/stories/pdf/otherdocuments/20130423_biofuelsstatement_en.pdf>; Intergovernmental Panel on Climate Change, Working Group III – Mitigation of Climate Change, "Addressing Transformation Pathways", Fifth Assessment Report (2014) at 91, online: <www.ipcc.ch/report/ar5/wg3/>; US Government Accounting Office, Center for Science, Technology, and Engineering, *Climate Engineering 25* (2011), online: <www.gao.gov/assets/330/322208.pdf>.

188 Actionaid, *Caught in the Net: How The 'Net-Zero Emissions' Will Delay Real Climate Action and Drive Land Grabs* (June 2015) at 7, online: <www.actionaid.org/publications/caught-net-how-net-zero-emissions-will-delay-real-climate-action-and-drive-land-grabs>. Some studies have attributed 30 percent of grain price increases from 2000 to 2007 to demand for biofuels; Mark W Rosegrant, "Biofuels and Grain Prices: Impacts and Policy Responses" (2008) at 2, online: International Food Policy Research Institute <www.ifpri.org/publication/biofuels-and-grain-prices>.

189 Bamikole Amigun, Josephine Kaviti Musango & William Stafford, "Biofuels and Sustainability in Africa" (2011) 15 Renewable & Sustainable Energy Rev 1360 at 1362.

190 International Bar Association, IBA Presidential Task Force on Climate Change Justice and Human Rights, "Achieving Justice and Human Rights in an Era of Climate Disruption" (July 2014) at 183, online: <www.ibanet.org/PresidentialTaskForceClimateChangeJustice2014Report.aspx>.

191 Oxfam International, "Climate Wrongs and Human Rights: Putting People at the Heart of Climate-Change Policy (2008) at 15–16. See also Center for Human Rights and Global Justice, *Foreign Land Deals and Human Rights: Case Studies on Agricultural and Biofuel Investment* (New York: NYU School of Law, 2010).

192 Hans Morten Haugen, "International Obligations and the Right to Food: Clarifying the Potentials and Limitations in Applying a Human Rights Approach When Facing Biofuels Expansion" (2012) 11 J Hum Rts 405 at 406.

193 Lorenzo Catula, Nat Dyer & Sonja Vermeulen, "Fuelling Exclusion? The Biofuels Boom and Poor People's Access to Land, International Institute for the Environment and Development and Food and Agriculture Organization" at 14, online: <pubs.iied.org/pdfs/12551IIED.pdf>; Secretariat of the Convention on Biological Diversity, *supra* note 185 at 56.

194 Actionaid, *supra* note 188 at 7. See also Evadné Grant & Onita Das, "Land Grabbing, Sustainable Development and Human Rights" (2015) 4:2 Transnatl Envtl L at 289–317; Lili Fuhr, *The Myth of Net-Zero Emissions* (10 December 2014), online: Heinrich Böll Foundation <www.boell.de/en/2014/12/10/myth-net-zero-emissions>.

195 Prakash Kashwan, "The Politics of Rights-Based Approach in Conservation" (2013) 31 Land Use Pol'y 613 at 622.

196 Raphael Slade, Ausilio Bauen & Robert Gross, "Global Bioenergy Resources" (2014) 4 Nature Climate Change 99 at 100.

sustenance.[197] For example, substantial portions of grazing lands are barren during the dry season in developing countries and are, thus, classified as "degraded." Yet, these lands are often productive during the rainy season and are relied upon for food and income by poor families.[198]

Finally, incentives for feedstock production may result in farmers converting substantial swaths of land from food crop production, reducing food supply for local populations.[199] For example, in one region of Brazil, conversion of land from cassava and rice production to oilseed for biofuel production undermined food security.[200] A recent study indicated that more than half of the world's bioenergy potential is centred in two regions with very large poor and food-vulnerable populations: Sub-Saharan Africa and Latin America and the Caribbean.[201]

BECCS would also have "a very large water footprint" when implemented at a scale of between 1.1 and 3.3 $GtCO_2$ equivalent per year.[202] By 2100, BECCS feedstock production at scale could require approximately 10 percent of the current evapotranspiration from all global cropland areas.[203] Markus Bonsch and others project that BECCS could entail water demands of the same magnitude as those of all current agricultural water withdrawals,[204] translating into nearly one-quarter of global annual runoff.[205] Moreover, water consumption for energy generation and carbon capture could have "intensive localized effects."[206] In a world of growing food demand, this could have serious implications, as maximum crop yields are only possible under conditions where water supplies are not restricted.[207] There is also concern that BECCS operations might reduce human access to clean water supplies, contaminate underground sources of drinking water, and result in diversion of water from ecosystems.[208] DAC operations would also be water-intensive, potentially requiring four percent of total current evapotranspiration used for crop cultivation.[209]

Finally, BECCS could "vastly accelerate the loss of primary forest and natural grassland."[210] This could result in habitat loss for many species and, ultimately, "massive" changes in species richness and abundance.[211] Moreover, the water demands associated with BECCS could have "substantial adverse impacts on freshwater ecosystems, particularly in South Asia.[212] Indeed, Phil Williamson concluded that large-scale deployment of BECCS could result in a greater diminution of terrestrial species than temperature increases of 2.8°C above pre-industrial levels.[213]

THE APPLICATION OF HUMAN RIGHTS TO CLIMATE GEOENGINEERING

Overview of the International Human Rights Framework

"Human rights are universal legal guarantees protecting individuals and groups against actions and omissions that interfere with fundamental freedoms, entitlements

197 Rachel Smolker & Almuth Ernsting, "BECCS (Bioenergy with Carbon Capture and Storage): Climate Saviour or Dangerous Hype?" (October 2012) at 8, online: Biofuelwatch <www.biofuelwatch.org.uk/2012/beccs_report/>; Secretariat of the Convention on Biological Diversity, *supra* note 185 at 32.

198 Slade, Bauen & Gross, *supra* note 196 at 103.

199 Lorenzo Cotula, Nat Dyer & Sonja Vermeulen, *Fueling Exclusion? The Biofuels Boom and Poor People's Access to Land* (2008) at 14, online: International Institute for Environment and Development & Food and Agriculture Organization of the United Nations <pubs.iied.org/pdfs/12551IIED.pdf>.

200 Marcus Vinicius Alves Finco & Werner Doppler, "Bioenergy and Sustainable Development: The Dilemma of Food Security and Climate Change in the Brazilian Savannah" (2010) 14 Energy for Sustainable Dev 194 at 198.

201 Helmut Haberl et al, "Global Bioenergy Potentials from Agricultural Land in 2050: Sensitivity to Climate Change, Diets and Yields" (2011) 35 Biomass & Bioenergy 4753 at 4762.

202 Pete Smith, "Soil Carbon Sequestration and Biochar as Negative Emission Technologies" (2016) 22:3 Global Change Biology 1315 at 1321.

203 Smith et al, *supra* note 181 at 47.

204 Bonsch et al, *supra* note 181 at 12.

205 Vaibhav Chaturvedi et al, "Climate Mitigation Policy Implications for Global Irrigation Water Demand" (2015) 20 Mitigation & Adaptation Strategies for Global Change 389 at 404.

206 Lydia J Smith & Margaret S Torn, "Ecological Limits to Terrestrial Biological Carbon Dioxide Removal" (2013) 118 Climatic Change 89 at 92.

207 P Moutonnet, "Yield Response Factors of Field Crops to Deficit Irrigation," FAO Corporate Document Repository at 3, online: <www.fao.org/docrep/004/y3655e/y3655e04.htm>.

208 Holly Jean Buck, "Rapid Scale-Up of Negative Emissions Technologies Social Barriers and Social Implications," (2016) Nature, DOI: <10.1007/s10584-016-1770-6> at 4; Kelsi Bracmort & Richard K Lattanzio, *Geoengineering: Governance and Technology Policy* (26 November 2013) at 12, online: Congressional Research Service <www.fas.org/sgp/crs/misc/R41371.pdf>.

209 Smith et al, *supra* note 181 at 46.

210 Williamson, *supra* note 181 at 154.

211 Wiltshire & Davies-Barnard, *supra* note 114 at 15. See also Gough & Vaughan, *supra* note 109 at 15; Secretariat of the Convention on Biological Diversity, *supra* note 185 at 38.

212 Bonsch et al, *supra* note 181 at 20.

213 Williamson, *supra* note 181 at 154.

and human dignity."[214] As such, they establish minimum standards for individuals and groups that cannot be contravened in the pursuit of aggregate societal benefits.[215] Most fundamentally, human rights protections seek to ensure that laws and political and social structures are grounded in moral reasons and moral discourse and are justifiable within a framework of appropriate legal and political structures.[216] Human rights provide a critical link between the protection of a vital interest and the imposition of a duty on others to protect and promote the interest.[217]

Human rights law has been established in a number of both legally binding and non-binding instruments. Binding instruments adopted by the UN General Assembly include the 1951 Convention Relating to the Status of Refugees,[218] the 1966 International Covenant on Civil and Political Rights (ICCPR),[219] the 1966 International Covenant on Economic, Social and Cultural Rights (ICESCR),[220] the 1969 International Convention on the Elimination of All Forms of Racial Discrimination,[221] the 1979 Convention on the Elimination of All Forms of Discrimination Against Women,[222] the 1989 Convention Concerning Indigenous and Tribal Peoples in Independent Countries,[223] the 1989 Convention on the Rights of the Child (CRC),[224] the 1990 International Convention on the Protection of the Rights of All Migrant Workers and Members of Their Families[225] and the 2006 Convention on the Right of Persons with Disabilities.[226]

Regional human rights instruments include the 1948 American Declaration of the Rights and Duties of Man,[227] the 1969 American Convention on Human Rights,[228] the 1988 Additional Protocol to the American Convention on Human Rights,[229] the 1950 European Convention for the Protection of Human Rights and Fundamental Freedoms,[230] the 1981 African Charter on Human and Peoples' Rights[231]

214 OHCHR, *Frequently Asked Questions on a Human Rights-Based Approach to Development Cooperation* (2006), at 1, online: <www.ohchr.org/Documents/Publications/FAQen.pdf>. See also Henry Shue, "Changing Images of Climate Change: Human Rights and Future Generations" (June 2014) 5 J Hum Rts & Envt 50 at 58.

215 Simon Caney, "Climate Change, Human Rights and Moral Thresholds" in Stephen Gardiner et al, eds, *Climate Ethics* (New York, NY: Oxford University Press, 2010) at 73–90, online: <www.humphreyfellowship.org/system/files/Caney_Climate_Change_Human_Rights%20_Moral_Thresholds.pdf>; Frédéric Mégret, "Nature of Obligations" in Daniel Moeckli, Sangeeta Shah & Sandesh Sivakumaran, eds, *International Human Rights Law,* 2nd ed (New York: Oxford University Press, 2010) at 129.

216 Rainer Frost, "The Justification of Human Rights and the Basic Right to Justification: A Reflexive Approach" (2010) 120:4 Ethics 711 at 734.

217 Charles Jones, "The Human Rights to Subsistence" (2013) 30:1 J Applied Phil 57 at 5.

218 Convention Relating to the Status of Refugees, 28 July 1951, 189 UNTS 137 (entered into force 22 April 1954), online: <www.unhcr.org/3b66c2aa10.html>.

219 *ICCPR,* 19 December 1966, 999 UNTS 171 (entered into force 23 March 1976), online: <www.ohchr.org/en/professionalinterest/pages/ccpr.aspx>.

220 *ICESCR,* 16 December 1966, 993 UNTS 3, 6 ILM 360 (entered into force 3 January 1976), online: <www.ohchr.org/EN/ProfessionalInterest/Pages/CESCR.aspx>.

221 International Convention on the Elimination of All Forms of Racial Discrimination, 21 December 1965, 660 UNTS 195 (entered into force 4 January 1969), online: <www.ohchr.org/EN/ProfessionalInterest/Pages/CERD.aspx>.

222 Convention on the Elimination of All Forms of Discrimination Against Women, 18 December 1979, 13 UNTS 1249 (entered into force 3 September 1981), online: <www.un.org/womenwatch/daw/cedaw/cedaw.htm>.

223 Convention concerning Indigenous and Tribal Peoples in Independent Countries (27 June 1989) (ILO No 169), 72 ILO Official Bull 59, 28 ILM 1382 (entered into force 5 September 1991), online: <www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C169>.

224 CRC, 20 November 1989, 1577 UNTS 3, 28 ILM 1456 (entered into force 2 September 1990), online: <www.ohchr.org/en/professionalinterest/pages/crc.aspx>.

225 International Convention on the Protection of the Rights of All Migrant Workers and Members of their Families, 18 December 1990, UN Doc A/RES/45/158, 30 ILM 1517 (entered into force 1 July 2003), online: <www2.ohchr.org/english/bodies/cmw/cmw.htm>.

226 Convention on the Right of Persons with Disabilities, 13 December 2006, UN Doc A/RES/61/106, Annex 1 (entered into force 3 May 2008), online: <www.un.org/disabilities/documents/convention/convoptprot-e.pdf>.

227 OAS, Inter-American Commission on Human Rights, *American Declaration of the Rights and Duties of Man,* OR OAS/Ser.L/V/I.4 Rev. 9 (2003), online: <www.oas.org/consejo/CAJP/Indigenous%20documents.asp>.

228 OAS, Inter-American Commission on Human Rights, American Convention on Human Rights, 21 November 1969, OAS Treaty Series No 36, 1144 UNTS 123, 9 ILM 99 (entered into force 18 July 1978), online: <www.oas.org/dil/treaties_B-32_American_Convention_on_Human_Rights.pdf>.

229 OAS, General Assembly, Additional Protocol to the American Convention on Human Rights in the Area of Economic, Social and Cultural Rights, 17 November 1988, OAS Treaty Series No 69, 28 ILM 156 (1989) (entered into force 16 November 1999), online: <www.oas.org/juridico/english/treaties/a-52.html>.

230 Council of Europe, European Convention for the Protection of Human Rights and Fundamental Freedoms, 4 November 1950, ETS 5, 213 UNTS 221 (entered into force 3 September 1953), reprinted in *Yearbook on Human Rights for* 1950 (New York: UN, 1952) at 418 [ECHR], online: <www.echr.coe.int/Documents/Convention_ENG.pdf>.

231 Organization of African Unity, *African Charter on Human and Peoples' Rights,* 27 June 1981, CAB/LEG/67/3 rev. 5, 21 ILM 58 (1982) (entered into force 21 October 1986), reprinted in Christof, Heyns, ed, *Human Rights Law in Africa,* vol 1 (The Hague: Kluwer Law International, 1996), online: <www.achpr.org/files/instruments/achpr/banjul_charter.pdf>.

and the Arab Charter on Human Rights.[232] States are also legally bound by human rights principles recognized by customary international law.[233] For example, and particularly relevant to the question of geoengineering, the right to self-determination under international law is recognized as "both individual from and a prerequisite for the realization of all other human rights."[234]

Non-legally binding instruments include the 1948 Universal Declaration of Human Rights (UDHR),[235] the 1986 Declaration on the Right to Development,[236] the 1993 Vienna Declaration and Programme of Action,[237] the 1995 Beijing Declaration and Platform for Action,[238] the 2007 Declaration on the Rights of Indigenous Peoples[239] and the 2012 Association of Southeast Asian Nations (ASEAN) Human Rights Declaration.[240] It should be recognized that the UDHR as a whole, or at least some portions, has been widely recognized as customary international law.[241]

The UDHR, ICESCR and ICCPR form the so-called "International Bill of Rights".[242] Virtually every state belongs to at least one of the two major human rights treaties, and more than 160 states belong to both the ICCPR and ICESCR.[243] All major emitters of GHG emissions are parties to both the ICESCR and ICCPR, with the exception of the United States, which has signed but not ratified the ICESCR, and China, which has signed but not ratified the ICCPR.[244]

Parties to human rights treaties are not only required to *respect* human rights, that is, to refrain from taking actions that might imperil the exercise of human rights, but they are also obligated to *protect* and *fulfill* these obligations.[245] The obligation to protect imposes a duty on states to take affirmative measures to deter, prevent, investigate and punish violations of human rights by private actors.[246] The obligation to fulfill imposes a duty on states to take positive actions to progressively facilitate the enjoyment of human rights.[247] This may include legal, judicial, policy and budgetary measures by state organs.[248]

In 1997, the UN Secretary-General launched an initiative to "mainstream" human rights as a cross-cutting concern of United Nations system activities.[249] Additional impetus for strengthening the application of human rights at the international and national level in recent years included

232 League of Arab States, *Arab Charter on Human Rights*, 22 May 2004 (entered into force 15 March 2008), reprinted in (2005) 12 Intl Hum Rts Rep, online: <www1.umn.edu/humanrts/instree/loas2005.html>.

233 Megan M Herzog, "Coastal Climate Change Adaptation and International Human Rights" in Randall S Abate, ed, *Climate Change Impacts on Ocean and Coastal Law* (New York: Oxford University Press, 2015) 593 at 599; Siobhán McInerney-Lankford, Mac Darrow & Lavanya Rajamani, "Climate Change: A Review of the International Legal Dimensions" (2011) at 21-5, online: The World Bank <siteresources.worldbank.org/INTLAWJUSTICE/Resources/HumanRightsAndClimateChange.pdf>.

234 Susannah Wilcox, "A Rising Tide: The Implications of Climate Change Inundation for Human Rights and State Sovereignty" (2012) 9 Essex Hum Rts Rev 2 at 6.

235 *Universal Declaration of Human Rights*, GA Res 217A(III), UNGAOR, 3rd Sess, Supp No 13, UN Doc A/810 (1948), online: <www.un.org/en/universal-declaration-human-rights/>.

236 *Declaration on the Right to Development*, GA Res 128, UNGAOR, 41st Sess, Supp No 53, UN Doc A/RES/41/128 (1986), online: <www.un.org/documents/ga/res/41/a41r128.htm>.

237 *Vienna Declaration and Programme of Action*, GA Res 121, UNGAOR, 48th Sess, UN Doc. A/CONF.157/23; 32 ILM 1661 (1993), online: <www.ohchr.org/EN/ProfessionalInterest/Pages/Vienna.aspx>.

238 *Beijing Declaration and Platform for Action adopted at the Fourth World Conference on Women*, GA Res 203, UN Doc. A/CONF. 177/20 (1995) and A/CONF. 177/20/Add. 1 (1995), online: <www.un.org/womenwatch/daw/beijing/pdf/BDPfA%20E.pdf>.

239 *United Nations Declaration on the Rights of Indigenous Peoples*, GA Res 295, UNGAOR, 61st Sess, Supp No 49, UN Doc A/RES/61/295, 46 ILM 1013 (2007), online: <www.un.org/esa/socdev/unpfii/documents/DRIPS_en.pdf>.

240 ASEAN, ASEAN Human Rights Declaration, 18 November 2012, online: <aichr.org/?dl_name=ASEAN-Human-Rights-Declaration.pdf>.

241 Vojin Dimitrijevic, "Customary Law as an Instrument for the Protection of Human Rights" (2006) ISPI Working Paper WP-7 at 8–12, online: <www.ispionline.it/it/documents/wp_7_2006.pdf>.

242 Mirko Bagaric & Penny Dimopoulos, "International Human Rights Law: All Show, No Go" (2005) 4 J Hum Rts 3 at 3.

243 John Knox, "Climate Ethics and Human Rights" (2014) 5 J Hum Rts & Envt 22 at 25.

244 *Ibid.*

245 Elisabeth Caesens & Maritere Padilla Rodríguez, *Climate Change and the Right to Food* (Berlin: Heinrich Böll Stiftung, 2009) at 43, online: <https://www.boell.de/sites/default/files/Series_Ecology_Volume_8_Climate_Change_and_the_Right_to_Food_0.pdf>.

246 The World Bank & Nordic Trust Fund, *Human Rights Impact Assessments: A Review of the Literature, Differences with Other Forms* (February 2013) at 5, online: <siteresources.worldbank.org/PROJECTS/Resources/40940-1331068268558/HRIA_Web.pdf>; James W Nickel, "How Human Rights Generate Duties to Protect and Provide" (1993) 15 Hum Rts Q 77 at 80–81.

247 OHCHR, "International Human Rights Law" online: <www.ohchr.org/EN/ProfessionalInterest/Pages/InternationalLaw.aspx>.

248 The World Bank & Nordic Trust Fund, *supra* note 246 at 4; United Nations, HRBA Portal, online: <hrbaportal.org/faq/what-kinds-of-human-rights-obligations-are-there>.

249 *Renewing the United Nations: a programme for reform*, GA Res 12, UNGAOR, 51st Sess, UN Doc A/RES/52/12 (1997) at paras 78, 79.

the Millennium Declaration of 2000[250] and the Secretary-General's 2002 reform program, which directed the OHCHR to work with UN partners to strengthen human rights at the country level.[251]

These efforts helped to lay the foundation for the development of international efforts to protect human rights potentially impacted by climate change, as well as response measures. In the next section, the potential threats that some climate geoengineering options might pose for the human rights protected in these agreements are outlined.

Potential Threats to Human Rights from Deployment of Geoengineering Options

THE RIGHT TO FOOD

The right to adequate food is established by a number of human rights instruments at the international and regional levels,[252] including the ICESCR, which seeks to protect "the fundamental right of everyone to be free from hunger."[253] The OHCHR has commented that states must take necessary actions to ensure freedom from hunger and access to adequate food, "even in times of natural or other disasters."[254] The ICESCR Committee General Comment No. 12 states that "accessibility encompasses both economic and physical accessibility."[255] Therefore, the comment continues, vulnerable groups such as displaced peoples and indigenous populations "may need attention through special [programs]."[256]

As indicated earlier, the deployment of either SAI or marine cloud brightening SRM approaches could adversely impact regional precipitation patterns, potentially threatening the food security of billions.[257] This could constitute a violation of the right to food, in terms of both potential deployers of such technologies and potentially affected states, whose governments might be obligated to take additional measures to protect the most vulnerable. Similarly, as discussed earlier, deployment of BECCS could raise food prices and/or displace agricultural production in ways that could also imperil food security and violate the right to food. Finally, should the termination effect described earlier manifest itself, the attendant rapid spikes in temperature might undermine food production in many parts of the world, including vulnerable portions of the South.[258]

THE RIGHT TO HEALTH

The right to health is included in a large number of human rights treaties and soft-law instruments,[259] as well as at least 115 national constitutions.[260] It is most comprehensively established in the ICESCR as "the right of everyone to the enjoyment of the highest attainable standard of physical and mental health."[261]

The ICESCR Committee interprets the right to health in General Comment No. 14 to include "a wide range of socio-economic factors that promote conditions in which people can lead a healthy life, and extends to the underlying determinants of health, such as...a healthy environment."[262] General Comment No. 14 further states that the right to health includes "a right to the enjoyment of a variety of facilities, goods, services and conditions necessary for the realization of the highest attainable

250 *United Nations Millennium Declaration,* GA Res 2, UNGAOR, 55th Sess, UN Doc A/Res/55/2 (2000), online: <un.org/millennium/declaration/ares552e.pdf>. The declaration's pertinent provisions on human rights include a call for respect for "all internationally recognized human rights" (Sec V, para 24) and efforts to strengthen the capacity of states to protect human rights (Sec V, para 25).

251 *Strengthening of the United Nations: an agenda for further change,* UNGAOR, 57th Sess, UN Doc A/57/387 (2002) at paras 45–51.

252 See e.g. *UDHR, supra* note 235, art 25 (part of the right to an adequate standard of living); CRC, *supra* note 224; International Convention on the Rights of Persons with Disabilities, *supra* note 229, art 25(f); Convention on the Elimination of all Forms of Discrimination Against Women, *supra* note 222, art 12; African Charter on Human and Peoples' Rights, *supra* note 231 (implicit in arts 4, 16, and 22).

253 ICESCR *supra* note 220, art 11(2).

254 OHCHR, *supra* note 6 at 9.

255 UNHRC, Committee on Economic, Social and Cultural Rights, General Comment 12: The Right to Adequate Food, 12 May 1999, UN Doc E/C/12/1999/5 at paras 3, 4, 13.

256 *Ibid*.

257 Royal Society, *supra* note 12.

258 Lili Xia et al, "Solar Radiation Management Impacts on Agriculture in China: A Case Study in the Geoengineering Model Intercomparison Project (GeoMIP)" (2014) 119 J Geophysical Research: Atmospheres 8695 at 8706.

259 *UDHR, supra* note 235, art 25; Convention on the Elimination of All Forms of Racial Discrimination, *supra* note 221, art 5(e)(iv); CRC, *supra* note 224, art 24; Convention on the Elimination of All Forms of Discrimination against Women, *supra* note 222, arts 11(1)(5), 12, 14(2)(b); International Convention on the Protection of the Rights of All Migrant Workers and Members of Their Families, *supra* note 225, arts 28, 43(e), 45(c); *African Charter on Human and Peoples' Rights, supra* note 231, art 16; Additional Protocol to the American Convention on Human Rights in the Area of Economic, Social and Cultural Rights, *supra* note 229, art 10; *Constitution of the World Health Organization (WHO),* 22 July 1946, 14 UNTS 185, Preamble.

260 OHCHR & World Health Organization, "The Right to Health: Fact Sheet No. 31" at 9, online: <www.ohchr.org/Documents/Publications/Factsheet31.pdf>.

261 *ICESCR, supra* note 220, art 12.

262 UN Committee on Economic, Social and Cultural Rights, General Comment No. 14: The Right to the Highest Attainable Standard of Health, 11 August 2000, UN Doc E/C/12/2000/4, online: <www.ohchr.org/Documents/Issues/Women/WRGS/Health/GC14.pdf>.

standard of health."[263] Additionally, states are required to take measures to ensure that private actors within their control do not violate the human right to health.[264]

Several climate geoengineering options could potentially affect the right to health. As indicated earlier, sulphur aerosol injection might delay replenishment of the ozone for decades, imperilling the health of millions. Moreover, to the extent that food production might be adversely impacted by deployment of SRM or CDR approaches, they would undermine one of the "underlying determinants of health."[265]

THE RIGHT TO WATER

A number of human rights instruments recognize the right to water.[266] The ICESCR Committee in General Comment No. 1 provides that the state's duty to respect the right to water requires refraining from interfering with the enjoyment of that right and protecting the right by adopting measures to restrain third parties from interfering with the right.[267]

In 2010, the UN General Assembly also officially recognized the "right to water and sanitation."[268] The UNHRC subsequently adopted HRC Resolution 15/9, which "affirms that the rights to water and sanitation are part of existing international law and confirms that these rights are legally binding" upon states parties to the ICESCR.[269] A number of regional courts have found that the right to safe drinking water and sanitation derives from other human rights, such as the rights to life, health and adequate housing,[270] even though the right is not explicitly mentioned in regional human rights instruments.[271]

The potential alteration of precipitation patterns associated with SRM approaches[272] could imperil the right to water for huge numbers of people. Marine cloud brightening involving the potential deposition of sea water could also reduce freshwater availability for islands where water resources are already severely constrained.[273] Moreover, the massive demands on water that some CDR approaches, such as BECCS, would entail, could similarly impact this right.

THE RIGHT TO LIFE

The UDHR explicitly recognizes the right to life,[274] as does article 6(1) of the ICCPR, which guarantees every human the "inherent right to life."[275] Many other international and regional human rights instruments also recognize the right to life.[276] Moreover, a large number of states also recognize the right to life through constitutional provisions or legislatively.[277]

Because the right to life is elemental to the protection of all others, no derogation is permitted by governments,

263 *Ibid.*

264 "The Right to Health: Fact Sheet No. 31", *supra* note 260 at 25.

265 UN Committee on Economic, Social and Cultural Rights, General Comment No. 14: The Right to the Highest Attainable Standard of Health, *supra* note 262 at para 11.

266 See e.g. Convention on the Elimination of All Forms of Discrimination against Women, *supra* note 227, art 14(2); International Convention on the Rights of Persons with Disabilities, *supra* note 226, art 28; CRC, *supra* note 224, arts 24, 27(e); International Labour Organization, Convention concerning Occupational Health Services, No 161, 25 June 1985, 71st ILC Sess (entered into force 17 February 1988) at art 5, online: <www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_INSTRUMENT_ID:312306>; Additional Protocol to the American Convention on Human Rights, *supra* note 229 at art 11(1); *Arab Charter on Human Rights*, *supra* note 232, art 39.

267 UN Committee on Economic, Social and Cultural Rights, General Comment No. 15: The Right to Water, 20 January 2003, UN Doc E/C.12/2002/11 (2003) at paras 21, 23.

268 *The Human Right to Water and Sanitation*, GA Res 64/292, UNGAOR, 64th Sess, Supp No 49, UN Doc A/RES/64/292 (2010), online: <www.un.org/es/comun/docs/?symbol=A/RES/64/292&lang=E>.

269 UNHRC, *Human Rights and Access to Safe Drinking Water and Sanitation*, 30 September 2010, UN Doc A/HRC/RES/15/9.

270 United Nations Human Rights, "The Right to Water: Fact Sheet No. 35" at 6, online: <www.ohchr.org/Documents/Publications/FactSheet35en.pdf>.

271 See e.g. Council of Europe, *European Social Charter*, 18 October 1961, 529 UNTS 89, ETS 35, online: <www1.umn.edu/humanrts/euro/z31escch.html>; American Convention on Human Rights, *supra* note 228 and the *African Charter on Human and Peoples' Rights*, *supra* note 231.

272 *Supra* notes 129–135 and accompanying text.

273 Caitlin G McCormack et al, "Key Impacts of Climate Engineering on Biodiversity and Ecosystems, with Priorities for Future Research" (2016) J Integrative Envtl Sci 1 at 12 (2016), online: <www.tandfonline.com/loi/nens20>.

274 *UDHR*, *supra* note 235, art 3.

275 *ICCPR*, *supra* note 219, art 6(1).

276 See e.g. *Arab Charter on Human Rights*, *supra* note 232 at art 5-6; Organization of African Unity, *African Charter on the Rights and Welfare of the Child*, 11 July 1990, OAU Doc CAB/LEG/24.9/49 (entered into force 29 November 1999), art 5, online: <www1.umn.edu/humanrts/africa/afchild.htm>; ECHR, *supra* note 230, art 2; *American Declaration of the Rights and Duties of Man*, *supra* note 227, art 1; American Convention on Human Rights, *supra* note 228, art 4.

277 See e.g. *Human Rights Act, 1998* (UK), c 42, Schedule 1, online: <www.legislation.gov.uk/ukpga/1998/42/schedule/1>; *Constitution Act, 1982*, being Schedule B to the *Canada Act 1982* (UK), c 11, s 7, online: <laws-lois.justice.gc.ca/eng/const/page-15.html#h-39>; Paraguay's Constitution of 1992 with Amendments Through 2011, art 4, online: <https://www.constituteproject.org/constitution/Paraguay_2011.pdf?lang=en>; The Constitution of India as of 9 November 2015, art 21, online: <lawmin.nic.in/olwing/coi/coi-english/coi-4March2016.pdf>.

even in times of purported public emergency.[278] The right has also been construed expansively on other axes. It requires states to "adopt positive measures" to protect the right.[279] It may also require application of a precautionary approach, meaning that governments must seek to prevent foreseeable harms or risks.[280] Moreover, the right to life has been construed to transcend mere protection from arbitrary violence, and it encompasses threats to the quality of life, including those related to environmental factors, human health and access to food and water.[281]

Many climate geoengineering options could threaten the right to life. These include potential impacts that might induce drought conditions, deplete the ozone layer, reduce food security or precipitate large and rapid pulses of warming.

Potential Threats to Biodiversity and Human Rights

As indicated above, BECCS could result in substantial diminution of biodiversity.[282] Other geoengineering approaches might also threaten species at both the local and global level. For example, many species might be unable to adapt, or migrate quickly enough, should the termination effect[283] occur in the context of SRM options.[284] SRM approaches might also alter global ocean circulation patterns through changing light availability, which is partially determined by incoming solar radiation.[285] Such changes in circulation and ocean nutrient upwelling could have potential impacts on biodiversity through the entire marine ecosystem.[286]

Loss of biological diversity could also undermine the right to health by leading to an increase in the transmission of infectious diseases, such as hantavirus, Lyme disease and schistosomiasis.[287] Moreover, products and services derived from biodiversity are a critical economic resource for many of the world's poor, including indigenous peoples.[288] Diminution of biodiversity through deployment of geoengineering options could undermine the right to livelihood,[289] which, in turn, is intimately linked to the human right to life and an adequate standard of living for health and well-being of individuals and families.[290] Loss of biodiversity could also undermine the right of indigenous peoples to access such resources.[291]

OPERATIONALIZING HUMAN RIGHTS PROTECTIONS UNDER THE PARIS AGREEMENT IN THE CONTEXT OF CLIMATE GEOENGINEERING

Overview/Application of the HRBA

As indicated at the outset, the Paris Agreement calls on its parties to take human rights into account "when taking action to address climate change."[292] This section of the report will suggest how this provision might be operationalized by the parties in the context of climate geoengineering.

The suggested framework outlined below for doing so is denominated a "human rights-based approach." As Margaux J. Hall explains, "[A] human rights-based approach is a conceptual framework for decision making

278 UNHRC, CCPR General Comment No. 6: Article 6 (Right to Life), 30 April 1982, art 6(1); UN Committee on Economic, Social and Cultural Rights, General Comment 14, *supra* note 262 at para 5 [UNHRC General Comment No. 6]. Indeed, some commentators argue that the right to life has *jus cogens* status. See BG Ramcharan, *The Right to Life in International Law* (Leiden, Netherlands: Martinus Nijhoff Publishers, 1985).

279 UNHRC General Comment No. 6, *supra* note 278, art 6.

280 *Valesquez Rodriquez Case* (29 July 1988) Inter-Am Ct HR (Ser C) No 4 at 70 to 71; United Nations Environment Program & Center for International Environmental Law, *UNEP Compendium on Human Rights and the Environment* (2014), summarizing *Budayeva and Others v. Russia* (2008), Eur Ct HR App No 15339/0 at 85, online: <www.unep.org/environmentalgovernance/Portals/8/publications/UNEP_Compendium_HRE.pdf>.

281 UNHRC General Comment No. 6, *supra* note 278, art 6; Randall S Abate, "Climate Change, the United States and the Impacts of Arctic Melting: A Case Study in the Need for Enforceable International Environmental Human Rights" (2007) 26:1 Fla A&M U Col L Scholarly Commons 4 at 11, online: <commons.law.famu.edu/cgi/viewcontent.cgi?article=1007&context=faculty-research>; *Indigenous Community Sawhoyamaxa v. Paraguay* (29 March 2006), 2006 Inter-Am Ct HR (Ser C) No 146 at para 153.

282 *Supra* notes 210–213 and accompanying text.

283 See the section titled "The Threat of a Termination Effect", *supra*.

284 McCormack et al, *supra* note 273 at 18.

285 *Ibid* at 12.

286 *Ibid*; Lynn M Russell et al, "Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan" (2012) 41 Ambio 350 at 361.

287 UNHRC, *supra* note 9 at 9.

288 Roubina Bassous/Ghattas, "Biodiversity and Human Rights from a Palestinian Perspective", online: The Applied Research Institute – Jerusalem/Society <www.arij.org/files/arijadmin/biodiversity.pdf>; Tim Hayward, "Biodiversity, Human Rights and Sustainability" (July 2001), online: Botanic Gardens Conservation International <www.bgci.org/education/article/0423>.

289 *UDHR*, *supra* note 235, art 25(1).

290 Ryan Hartzell C Balisacan, "Harmonizing Biodiversity Conservation and the Human Right to Livelihood: Towards a Viable Model for Sustainable Community-Based Ecotourism Using Lessons from the Donsol Whale Shark Project" (2012), 57 Ateneo LJ 423 at 438.

291 Convention concerning Indigenous and Tribal Peoples in Independent Countries, *supra* note 223, art 15(1); *United Nations Declaration on the Rights of Indigenous Peoples*, *supra* note 239, art 8(2)(b).

292 Paris Agreement, *supra* note 7.

that is normatively grounded in international human rights principles. The approach focuses not only on substantive outcomes and promoting and protecting human rights; it also closely investigates the processes that underlie human rights-related decision making."[293]

The hallmark of the HRBA is a focus "on the relationship between the rights-holder and the duty-bearer and revealing gaps in legislation, institutions, policy and the possibility of the most vulnerable to influence decisions that have impact on their lives."[294] An HRBA establishes a normative framework "for addressing systematic and structural injustices, social exclusions and human rights repressions." [295]

The emphasis of the HRBA on effective processes to address and integrate human rights at all governmental scales[296] is particularly important, since legal institutions are only able to respond to a small percentage of rights violations.[297] The HRBA has been embraced by international, national and subnational governmental and non-governmental organizations in a wide array of contexts, including, health, development and environmental protection.[298] The parties to the Paris Agreement can facilitate this process under any circumstances where a party, or group of parties, would seek to implement geoengineering responses to climate change.

Drawing upon guidelines developed by human rights and development institutions,[299] an HRBA to climate geoengineering research and potential deployment should include the following elements: identification of the human rights claims of rights-holders and corresponding human rights obligations of duty-bearers; assessment of the capacity of rights-holders to exercise their rights and duty-bearers to fulfill their respective obligations, as well as strategies to bolster capacities; establishment of a program to monitor and evalutate both outcomes and processes, guided by human rights standards and principles; and collaboration to ensure that programs are informed by recommendations from international human rights bodies and mechanisms.

IDENTIFICATION OF HUMAN RIGHTS CLAIMS AND OBLIGATIONS

This paper has generally outlined some of the potential human rights that might be affected by research and potential deployment of climate geoengineering technologies and some of the groups that might be affected. An HRBA would demand, and seek to facilitate, a much more granular inquiry by seeking to identify the specific potential impacts of discrete climate geoengineering technologies and associated potential human rights considerations, as well as the specific groups likely to be impacted.

A salutary method to effectuate this goal would be to mandate conducting a human rights impact assessment (HRIA) in any case where a geoengineering research program or deployment might have serious impacts on human rights. HRIAs are assessment protocols that assess the consistency of policies, legislation, projects and programs with human rights.[300] The HRIA is a particularly appropriate instrument in the context of emerging high-risk technologies such as geoengineering in that its focus is not on past violations but rather on developing tools to avoid violations of rights in the future.[301]

HRIAs could be conducted in conjunction with environmental impact assessments (EIAs). EIAs almost assuredly would be legally mandated at the national and/or international level for any geoengineering research

293 Margaux J Hall, "Advancing Climate Justice and the Right to Health Through Procedural Rights" (June 2014) 16(1) Health & Hum Rts 8 at 15. See also Ken Conca, *An Unfinished Foundation* (New York, NY: Oxford University Press, 2015) at 147. HRBAs' value "does not come from formal affirmations of such synergies, or even from the articulation of obligations facing states. It comes, ultimately, from the empowerment of people."

294 Alessandra Lundström Sarelin, "Human Rights-Based Approaches to Development Cooperation, HIV/AIDS, and Food Security" (2007) 29:2 Hum Rts Q 460 at 479, online: <courses.arch.vt.edu/courses/wdunaway/gia5434/sarelin07.pdf>.

295 Damilolo S Olawuyi, "Advancing Climate Justice in International Law: An Evaluation of the United Nations Human Rights-Based Approach" (2016) 11:1 Fla A&M UL Rev 1 at 9.

296 Mariya Gromilova, "Revisiting Planned Relocation as a Climate Change Adaptation Strategy: The Added Value of a Human Rights-Based Approach" (2014) 10:1 Utrecht L Rev 76 at 91.

297 Stephen Turner, *A Global Environmental Right* (New York, NY: Routledge, 2014) at 29-30.

298 Aled Dilwyn Fisher, *A Human-Rights Based Approach to Environment and Climate Change* (March 2014), online: GI-ESCR Practitioner's Guide <globalinitiative-escr.org/wp-content/uploads/2014/03/GI-ESCR-Practitioners-Guide-Human-Rights-Environment-and-Climate-Change.pdf>; Leslie London, "What Is a Human Rights Based Approach to Health, and Does It Matter?" (January 2008) 10:1 Health & Hum Rts 65–80, online: <https://www.researchgate.net/profile/Leslie_London/publication/46287024_What_is_a_human-rights_based_approach_to_health_and_does_it_matter/links/54de290d0cf23bf2043af813.pdf>; United Nations, HRBA Portal, "The Human Rights Based Approach to Development Cooperation: Toward a Common Understanding Among UN Agencies", online: <hrbaportal.org/the-human-rights-based-approach-to-development-cooperation-towards-a-common-understanding-among-un-agencies>. Andrea Cornwall & Celestine Nyamu-Musembi, "Putting the 'Rights-Based Approach' to Development into Perspective" (2004) 25:8 Third World Q 1415–1437, online: <courses.arch.vt.edu/courses/wdunaway/gia5434/cornwall.pdf>.

299 International Human Rights Law Clinic, *supra* note 11 at 15; UN High Commissioner for Refugees, *Climate Change, Natural Disasters and Human Displacement: A UNHCR Perspective* (14 August 2009) at 11, online: <www.unhcr.org/4901e81a4.pdf>.

300 The World Bank & Nordic Trust Fund, *supra* note 246 at 1.

301 *Ibid.*

program or deployment that might have substantial environmental impacts.[302] There are four elements that a geoengineering HRIA should include. Each is discussed in turn.

First, a geoengineering HRIA should include a scoping process that would identify rights-holders and duty-bearers and would develop relevant indicators to use in the process to help assess potential impacts and their relevance to the human rights interests of rights-holders.

In identifying rights-holders, an HRBA focuses on protection of the rights of excluded and marginalized populations, including those whose rights are most likely to be threatened.[303] An HRBA also emphasizes that rights-holders are not protected merely by the "benevolence" of states but rather that governments are required to "work consistently towards ending denials or violations of human rights."[304] The HRIA process should reflect these principles also.

Initial development of human rights indicators began in the 1990s as a means of assessing compliance with human rights treaties vis-à-vis projects or programs.[305] Indicators fall into three broad categories: structural, which seek to assess state intent to comply with human rights law; process, which measure state efforts to implement human rights, as well as steps taken to ensure protection of rights, including transparency, accountability of institutions and existence of consultations with stakeholders; and outcome, which measure state human rights performance.[306] Indicators focus on capturing quantitative information on human rights; however, qualitative statements can complement data by putting information into perspective.[307] For example, a pertinent HRIA indicator in the context of BECCS could be the amount of croplands that might be diverted in a state for bioenergy feedstocks and the potential impacts on local food production. This quantitative data might be supplemented by testimony from indigenous tribes and their experience in protecting their interests in a region where such projects are being developed.

Second, a geoengineering HRIA should include an evidence-gathering process to help assess the potential impacts of geoengineering research or deployment.

One critical requirement of the HRBA process would be greatly enhanced scientific understanding of the impacts of specific geoengineering options, including regional impacts that might adversely impact specific potential rights-holders. For example, in the context of SRM approaches, general circulation models (GCMs)[308] would play a critical role in preliminary assessments. However, GCMs currently do not perform well in modelling regional impacts of SRM geoengineering options, especially in terms of the critical consideration of precipitation.[309] An HRBA would exert pressure on researchers and policy makers to conduct such research to identify potential "winners" and "losers." This might include enhanced funding of the Geoengineering Model Intercomparison Project (GeoMIP), which seeks to establish a consensus among climate models in terms of geoengineering technologies.[310]

302 A Neil Craik et al, *Procedural Governance of Field Experiments in Solar Radiation Management* (March 2015), IASS/CIGI Workshop Report at 10, online: <https://www.cigionline.org/publications/procedural-governance-of-field-experiments-solar-radiation-management>. See also *Case Concerning Pulp Mills on the River Uruguay (Argentina v Uruguay)* [2010] ICJ Rep (20 April 2010) at paras 204, 205; environmental impact assessment required "where there is a risk that the proposed industrial activity may have a significant adverse impact in a transboundary context". UNFCCC, *supra* note 2 at art 4(1)(f); parties to utilize processes such as EIAs to minimize impacts of projects to mitigate or adapt to climate change. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, *Assessment Framework for Scientific Research Involving Ocean Fertilization, supra* note 28 at 6-18. Convention on Biological Diversity, 10th meeting of the Conference of the Parties, COP10 Decision X/33 (2010); requiring *ex ante* environmental assessment of any proposed small-scale geoengineering scientific research. State of Rhode Island, General Assembly, *The Climate Geoengineering Act of 2016*, House Bill 7578 (2016), online: <https://legiscan.com/RI/text/H7578/id/1334695>; proposed bill would, inter alia, require environmental impact assessment for geoengineering research with potential atmospheric impacts above a critical threshold.

303 OHCHR, *Frequently Asked Questions on a Human Rights-Based Approach to Development Cooperation* (2006) at 16, online: <www.ohchr.org/Documents/Publications/FAQen.pdf>.

304 UNICEF, *A Human Rights-Based Approach to Programming for Material Mortality Reduction in a South Asian Context* (2003) at 25, online: <www.unicef.org/rosa/HumanRights.pdf>.

305 Gaither de Beco, "Human Rights Indicators: From Theoretical to Practical Application" (2013) 5:2 J Hum Rts Prac 380 at 380.

306 United Nations Human Rights Instruments, "Report on Indicators for Promoting and Monitoring the Implementation of Human Rights" (6 June 2008) HRI/MC/2008/3 at 10–13, online: <www2.ohchr.org/english/issues/indicators/docs/HRI.MC.2008.3_en.pdf>. Oliver De Schutter, "A Human Rights Approach to Trade and Investment Policies" (November 2008), online: Conference on Confronting the Global Food Challenge <www.iatp.org/files/451_2_104504.pdf> at 18.

307 de Beco, *supra* note 305 at 383.

308 General circulation models seek to numerically simulate the response of the global climate system to perturbations, such as GHG emissions, or in the case of solar radiation management, interventions such as SAI, by representing pertinent physical processes in the atmosphere, oceans, cryosphere and land surfaces. The climate is depicted through a three-dimensional grid laid over the earth. Intergovernmental Panel on Climate Change, "What is a GCM?", online: <www.ipcc-data.org/guidelines/pages/gcm_guide.html>. See also B Geerts & E Linacre, "What are General Circulation Models?", online: University of Wyoming <www.as.uwyo.edu/~geerts/cwx/notes/chap12/nwp_gcm.html>.

309 Peter J Irvine, Andy Ridgwell & Daniel J Lung, "Assessing the Regional Disparities in Geoengineering Impacts" (2010) 37 Geophysical Research Letters L18702 at 1.

310 GeoMIP, "Welcome", online: <climate.envsci.rutgers.edu/GeoMIP/index.html>.

Third, a geoengineering HRIA should include an *ex ante* deliberative process between rights-holders and duty-bearers that would help identify specific concerns of rights-holders and duty-bearers.

A critical *sine qua non* of the legitimacy of any potential governance architecture for climate geoengineering is engagement of populations in regions where impacts are likely to be most extreme, especially in developing countries.[311] This participatory component of the HRIA process could help to facilitate this by operationalizing procedurally oriented human rights provisions, including the right to information and the right to public participation.

The right to access pertinent information is critical for members of potentially affected publics to be heard and to potentially influence decision-making processes.[312] The generalized right of access to information by the public is recognized in the UDHR,[313] as well as in the ICCPR.[314] Moreover, there is support in a number of instruments for the more particularized right of access to information about environmental and climate matters, including in the UNFCCC,[315] the Paris Agreement,[316] and the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters.[317] The UN special rapporteur for human rights and the environment has also stated that "in order to protect human rights from infringement through environmental harm, States should provide access to environmental information and provide for the assessment of environmental impacts that may interfere with the enjoyment of human rights."[318]

The right to public participation is provided for in the UDHR,[319] as well as in many other human rights instruments.[320] It is also recognized in pertinent environmental instruments, including the UNFCCC,[321] the Paris Agreement,[322] the World Charter for Nature[323] and the Aarhus Convention.[324]

In developing this component of the HRIA, every effort should be made to go beyond merely soliciting public opinion on geoengineering issues, usually characterized as public communication or public consultation,[325] to the establishment of large-scale public deliberative processes. Public deliberative processes seek to afford citizens, or a representative subset thereof, the opportunity to discuss, exchange arguments and deliberate on critical issues,[326] as well as to seek to persuade one another of the judiciousness of their solutions.[327] Public deliberative processes emphasize the role of debate and discussion to facilitate the formulation of well-informed opinion and a reflexive process whereby participants are open to revision of their opinions based upon their interaction with others.[328] As

311 Nick Pidgeon, "Deliberating Stratospheric Aerosols for Climate Geoengineering and the SPICE Project" (2013) 3 Nature Climate Change 451 at 454.

312 UNHRC, *supra* note 9 at 15.

313 *UDHR*, *supra* note 235, art 19.

314 *ICCPR*, *supra* note 219, art 19.

315 UNFCCC, *supra* note 2, art 6(a)(ii).

316 Paris Agreement, *supra* note 7, art 12.

317 Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, 25 June 1998, 2161 UNTS 447; 38 ILM 517 art 4(4) (entered into force 30 October 2001) [Aarhus Convention].

318 UNHRC, *Report of the Independent Expert on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment*, UNHRCOR, 25th Sess, U.N Doc A/HRC/25/53 (2013) at 9.

319 *UDHR*, *supra* note 235, art 21.

320 *ICCPR*, *supra* note 219, art 25; *African Charter on Human and People's Rights*, *supra* note 231, art 13; *American Declaration of the Rights and Duties of Man*, *supra* note 227, art 20; *American Convention on Human Rights*, *supra* note 228, art 23; Declaration on the Right to Development, A/RES/41/128, 4 December 1986, 97th Plenary Meeting, art 1(1), online: <www.un.org/documents/ga/res/41/a41r128.htm>.

321 UNFCCC, *supra* note 2, art 6(a)(iii). See also UNFCCC, *Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007*, 14 March 2008, UN Doc FCCC/CP/2007/6/Add.1, Decision 9/CP.13, *Amended New Delhi Work Programme on Article 6 of the Convention*, Annex, at para 15, online: <unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf#page=37>.

322 Paris Agreement, *supra* note 7, art 12.

323 *World Charter for Nature*, GA Res 37/7, UNGAOR, 37th Sess, Supp No. 51, UN Doc A/37/51 (1982) at 17.

324 Aarhus Convention, *supra* note 317, arts 3(2), 6.

325 "In public communication, information is conveyed from the sponsors of the initiative to the public.... In public consultation, information is conveyed from members of the public to the sponsors of the initiative, following a process initiated by the sponsor. Significantly, no formal dialogue exists between individual members of the public and sponsors. The information elicited from the public is believed to represent currently help opinions on the topic in question." Gene Rowe & Lynn J Frewer, "A Typology of Public Engagement Mechanisms" (2005) 30 Sci, Tech & Hum Values 251 at 254–55, online: <web.iaincirebon.ac.id/ebook/moon/CivilSociety/A%20Typology%20of%20Public%20Engagement%20Mechanisms.pdf>.

326 Paul Anderson, "Which Direction for International Environmental Law?" (2015) 6:1 J Hum Rts & Envt 98 at 121.

327 *Ibid*. J Dryzek, "Ecology and Discursive Democracy" in M O'Connor, ed, *Is Capitalism Sustainable? Political Economy and the Politics of Ecology* (New York and London: Guilford Press, 1994) 176.

328 S Chambers, *Reasonable Democracy: Jürgen Habermas and the Politics of Discourse* (Ithaca, NY: Cornell University Press, 2003) 309.

such "deliberation is not so much a form of discourse or argumentation as a joint, cooperative activity."[329]

The format of deliberative exercises can facilitate critical scrutiny of pre-analytic assumptions underpinning our framing of data and other sources of knowledge, and can foster self-awareness and reflection by key actors, including science and policy institutions.[330] This can both enhance the quality of the problem-solving and decision-making process, as well as bolster the legitimacy of policy decisions.[331]

Such a reflexive process, if conducted at regional and/or national scales, might help society "steer clear of the pitfalls of a grand narrative, as it would manifest differently in different cultures and ecosystems."[332] This would open up the possibility of developing a suite of geoengineering approaches, each of which are most attuned to the needs of individual countries or regions, such as SAI in the Arctic or marine cloud brightening in the northeast Pacific.[333]

Fourth, a geoengineering HRIA should include analysis and recommendations. This element of the HRIA process should include assessment of the human rights impacts of the proposed geoengineering intervention (research or deployment), and an assessment of state responsibilities to respect, protect and fulfill human rights in this context. This step should also include the critical element of the development of recommendations to avoid or ameliorate potential impacts on human rights or alternative means to achieve climatic goals that would avoid human rights violations. This obligation of outlining and discussing mitigation and alternative options is also an important component of environmental impact assessments at both the international and national levels.[334]

For example, many proponents contend that SRM climate geoengineering options might need to be deployed to respond to "climate emergencies."[335] The most frequently cited scenarios are those in which there is the imminent threat of temperatures exceeding critical climatic thresholds, manifesting themselves, for example, in a dramatic increase in the decay rate of large ice sheets, widespread bleaching of coral reefs or other abrupt and potentially non-linear changes in the climate system.[336] However, there may also be alternatives to climate geoengineering that can help us avoid passing critical thresholds as we make a transition to a decarbonized world economy without threatening human rights. For example, a recent study by the UNEP and the WMO concluded that implementation of a full set of measures to reduce

329 J Bohman, *Public Deliberation: Pluralism, Complexity, and Democracy* (Cambridge, MA: The MIT Press, 2000) at 27.

330 Jason Chilvers, "Reflexive Engagement? Actors, Learning, and Reflexivity in Public Dialogue on Science and Technology" (2012) 35:3 Science Communications 283 at 287; P Macnaghten et al, "Responsible Innovation Across Borders: Tensions, Paradoxes and Possibilities" (2014) 1:2 J Responsible Innovation 191 at 194; Bronislaw Szerszynski & Maialen Galarraga, "Geoengineering Knowledge: Interdisciplinarity and the Shaping of Climate Engineering Research" (2013) 45 Envt & Planning A 2817 at 2819.

331 Burns, *supra* note 23 at 268, 269.

332 Holly Joan Buck, "Geoengineering: Re-Making Climate for Profit or Humanitarian Intervention?" (2012) 43 Dev & Change 253 at 268.

333 *Ibid.*

334 The Pew Charitable Trusts, "High Seas Environmental Assessments", 15 March 2016, online: <www.pewtrusts.org/en/research-and-analysis/issue-briefs/2016/03/high-seas-environmental-impact-assessments>; Neil Craik, *The International Law of Environmental Impact Assessment* (Campbridge: Cambridge University Press, 2008) 67; Convention on Environmental Impact Assessment in a Transboundary Context, 25 February 1991, 1989 UNTS 310, 30 ILM 800 (entered into force 10 September 1997) at art 5(a), online: <unece.org/fileadmin/DAM/env/eia/documents/legaltexts/Espoo_Convention_authentic_ENG.pdf>; *National Environmental Policy Act of 1969*, 42 USC § 4321 (1969) at §4332, online: <elr.info/sites/default/files/docs/statutes/full/nepa.pdf>; *National Wildlife Federation v. National Marine Fisheries Service* (2016), 2016 WL 2353647 (Oregon Dist Ct) at 59; EC, *Directive 2014/52/EU of the European Parliament and Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment*, [2014] OJ L124/1 at art 5(1)(d), Annex IV.4.

335 Lee Lane, "Researching Solar Radiation Management as a Climate Policy Option" (5 November 2009), online: American Enterprise Institute for Public Policy Research <geoengineeringwatch.org/documents/peterson/Geoengineering%20U.S.%20House%20Hearing%20November%205,%202009%20LaneTestimony%20from%20A.E.I.pdf>. See also Rob Bellamy, Jason Chilvers & Naomi E Vaughan, "Deliberative Mapping of Options for Tackling Climate Change: Citizens and Specialists 'Open Up' Appraisal of Geoengineering" (September 2014) Pub Understanding Sci 1 at 2; David G Victor et al, "The Geoengineering Option: A Last Resort Against Global Warming?" (March/April 2009) 88:2 Foreign Aff 64 at 66.

336 Joshua B Horton, "The Emergency Framing of Solar Engineering: Time for a Different Approach" (2015) 2:2 Anthropocene Rev 147 at 148; Sanna Joronen, "Climate Change and Ethics of Geoengineering – Implications of Climate Engineering Ethics" (2015) 32 Reports from the Department of Philosophy, University of Turku at 72-3, online: <https://www.doria.fi/bitstream/handle/10024/117261/dissertation2015Joronen_Sanna.pdf?sequence=2>.

black carbon and tropospheric ozone emissions by 2030[337] could reduce the potential increase in global temperature projected for 2050 by 50 percent, with substantial net economic benefits.[338] This would translate into a reduction of temperatures by 0.5°C globally by 2050,[339] and 0.7°C in the Arctic by 2040.[340] In the latter context, that would offset all, or a substantial portion, of the reference warming scenario of 0.7°C to 1.7°C by 2040.[341] Moreover, these policy measures would yield substantial co-benefits, including the avoidance of more than two million premature deaths and the annual loss of one to four percent of global production of maize, rice, soybeans and wheat.[342] An HRIA process might help to ensure that such options are thoroughly vetted.

Alternatively, an HRIA process might lead the world community to opt for a strictly limited application of geoengineering options concordant with protection of human rights. For example, SRM approaches could be used simply to facilitate "peak shaving." Peak shaving would entail limited deployment of SRM technologies to ameliorate the worst potential impacts of peak GHG emissions, while mandating an ambitious program of mitigation and adaptation.[343] By illustration, Michael Zürn and Stefan Schäfer suggested limiting alteration of the radiation balance to no more than 1 W/m^2 as a means to greatly reduce the potential negative side effects of SRM deployment.[344] Similar scenarios have been advanced by Douglas G. MacMartin, Ken Caldeira and David W. Keith[345] and Takanobu Kosugi.[346] Similar standards might be established for CDR options.

ASSESSMENT OF CAPACITIES AND STRATEGIES TO BOLSTER CAPACITIES

Capacity, broadly defined, is a critical consideration in determining the ability of duty-bearers to meet their obligations and rights-holders to claim their rights.[347] In terms of duty-bearers, an HRBA in the context of climate

337 Black carbon is a constituent element of the combustion product known as soot. Indoor sources are primarily due to cooking with biofuels, including dung, wood and crop residue. The primary outdoor source is attributable to fossil fuel combustion (diesel and coal), open biomass burning and cooking with biofuels. V Ramanathan & G Carmichael, "Global and Regional Climate Changes Due to Black Carbon" (2008) 1 Nature Geoscience 221 at 221. Recent studies indicate that black carbon emissions are the second largest contributor to global warming, as much as 55 percent of the forcing associated with carbon dioxide. TC Bond, "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment" (2013) 118 J Geophysical Research: Atmospheres 5380 at 5380: "Reducing Black Carbon, or Soot, May Be Fastest Strategy for Slowing Climate Change" (22 April 2008), IGSD/INECE Climate Briefing Note, online: <www.igsd.org/docs/BC%20Briefing%20Note%2027Mar08.pdf>. Measures to reduce black carbon that may prove highly cost-beneficial include the use of diesel particulate filters for diesel engines and industrial sources, as well as other industrial control technologies, widespread adoption of advanced cook stoves, and banning or reducing the burning of agricultural waste and fuel switching; Drew Shindell et al, "Simultaneously Mitigating Near-Term Climate Change and Improving Health and Food Security" (2012) 335 Science 183 at 183; US Environmental Protection Agency, "Mitigating Black Carbon", online: <https://www3.epa.gov/blackcarbon/mitigation.html>; US Department of State, "The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants" (6 February 2012), online: <//www.state.gov/r/pa/prs/ps/2012/02/184055.htm>. Tropospheric ozone, precipitated by sunlight-driven oxidation of so-called ozone pre-cursors, especially methane, exerts a substantial short-term greenhouse effect. UNEP, *Near-Term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers* vii (2011), online: <www.unep.org/pdf/Near_Term_Climate_Protection_&_Air_Benefits.pdf>. The primary methods to reduce tropospheric ozone involve reducing methane emissions; Environmental and Energy Study Institute, "Short-Lived Pollutants: Why are they Important?" (February 2013), online: <www.eesi.org/files/FactSheet_SLCP_020113.pdf>. Methods to reduce methane emissions include diversion of waste into sanitary landfills or, for onsite power generation, capturing fugitive emissions from energy production and other sources, capturing emissions from livestock manure and intermittent aeration of flooded rice paddies; Institute for Governance and Sustainable Development, "Primer on Short-Lived Climate Pollutants" (February 2013), online: <igsd.org/documents/PrimeronShort-LivedClimatePollutantsFeb192013.pdf>; World Bank, "Integration of Short-Lived Climate Pollutants in World Bank Activities" (June, 2013), online: <www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/08/19/000333037_20130819113818/Rendered/PDF/804810WP0G80Re00Box0379805B00OUO090.pdf> at 21.

338 UNEP, "Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers" (February 2011) UN Doc UNEP/GC/26/INF/20 at 3, online: <www.unep.org/gc/gc26/download.asp?ID=2197>. See also Shindell et al, *supra* note 337 at 187–88; Almut Arneth et al, "Clean the Air, Heat the Planet?" (2009) 326 Science 672 at 672.

339 UNEP, *supra* note 338.

340 UNEP and WMO, "Integrated Assessment of Black Carbon and Tropospheric Ozone" (2011), online: <www.unep.org/dewa/Portals/67/pdf/BlackCarbon_report.pdf> at 246.

341 *Ibid.*

342 *Ibid.* See also Jianfei Peng et al, "Markedly Enhanced Absorption and Direct Radiative Forcing of Black Carbon Under Polluted Urban Environments" (2016) 113:16 Proceedings Natl Acad Sci 4266 at 4268, 4269.

343 Horton, *supra* note 336 at 150.

344 Michael Zürn & Stefan Schäfer, "The Paradox of Climate Engineering" (2013) 4:3 Global Pol'y 1 at 9.

345 Douglas G MacMartin, Ken Caldeira & David W Keith, "Solar Geoengineering to Limit the Rate of Temperature Change" (2014) 372 Philosophical Transactions Royal Soc'y A 20140134 at 6–11; limiting magnitude and duration of deployment of SRM with objective of restricting decadal temperature increases to 0.1°C could reduce risks of adverse impacts, such as depletion of the ozone layer.

346 Takanobu Kosugi, "Fail-Safe Solar Radiation Management Geoengineering" (2013) 18 Mitigation Adaptation Strategies Global Change 1141 at 1159. *See also* S. Tilmes, B.M. Sanderson & B.C. O'Neill, "Climate Impacts of Geoengineering in a Delayed Mitigation Scenario," Geophysical Research Letters (2016), DOI: <10.1002/2016GL070122>.

347 *Methods to Monitor the Human Right to Adequate Food, Volume II* (Rome: Food and Agricultural Organization of the United Nations, 2008) at 38; Urban Jonsson, *Human Rights Approach to Development Programming*, (2003), online: UNICEF <www.unicef.org/rightsresults/files/HRBDP_Urban_Jonsson_April_2003.pdf> at 15.

geoengineering should include an assessment of human resources, most specifically, the capacity to recognize and understand the human rights implications of deployment of potential geoengineering technologies. It should also include an assessment of the economic resources of duty-bearers, with an eye to ensuring safe deployment of technologies, the capability for effective monitoring and the capability to compensate those who might experience contravention of their human rights.

In terms of rights-holders, an HRBA assessment of capacity should include the determination of rights-holders' access to pertinent information, particularly for marginalized and traditionally excluded groups, and assessment of their capabilities to organize and participate in deliberative forums related to climate geoengineering and to obtain redress for violations.[348] Both duty-bearers and rights-holders should subsequently focus on developing strategies to strengthen capacities, including through provision of financial resources, training of personnel and pertinent scientific research.

ESTABLISHMENT OF MONITORING AND EVALUATION PROGRAMS

Implementation of monitoring programs should include the use of a *role and capacity analysis* to assess the obligations of institutions at the international and national level to monitor the impacts of geoengineering, as well as their capacity, and an *analysis of existing information systems and networks* to assess critical information gaps for effective monitoring by decision makers, rights-holders and rights-bearers.[349]

One example where monitoring could be particularly salutary is in terms of deployment of BECCS. Projections of potentially sustainable levels of bioenergy deployment are "systematically optimistic" and are not based on empirical observations or practical experience. [350] Raphael Slade, Ausilio Bauen and Robert Gross suggest fostering "learning by doing" through close monitoring of incremental efforts to expand the role of biomass in energy production."[351] Close monitoring of the first few exajoules of energy crops would help us realistically assess purported benefits of integrated crop and energy production and the sustainability of energy crop extension into allegedly marginalized, degraded and deforested lands.

COLLABORATION WITH HUMAN RIGHTS BODIES

The UNFCCC would clearly benefit from collaboration with human rights bodies. This could include UN bodies, such as: the OHCHR and the UNHRC; human rights treaty bodies, such as the Human Rights Committee, which monitors implementation of the ICCPR by its parties, and the Committee on the Rights of the Child; regional bodies, such as the Inter-American Commission on Human Rights and the African Commission on Human and People's Rights; and non-governmental organizations, such as Human Rights Watch and the International Red Cross. Collaboration should also be explored with other organizations that may help to inform the process, such as the Global Bioenergy Partnership (GBEP), comprised of both state and non-state actors. The GBEP has developed a set of sustainability indicators intended to inform decision making and to foster sustainability, including in the context of socio-economic considerations.[352]

Moreover, the OHCHR has called for integrating an HRBA into climate change mitigation and adaptation policies.[353] Thus, the parties to the Paris Agreement could likely call upon the OHCHR, as well as on other human rights agencies and organizations, for assistance in development of the HRBA.[354] Human rights institutions could also help fill in interstices by utilizing the HRBA's mechanisms for investigating human rights issues, including special procedures, the establishment of special advisory committees and universal periodic review.[355]

Implementing the HRBA for Climate Geoengineering within the Paris Agreement

The optimal method to facilitate the HRBA process under the Paris Agreement would be to establish a human

348 United Nations Development Program (UNDP), *Applying a Human Rights-Based Approach to Development Cooperation and Programming: A UNDP Capacity Development Resource* (2006), online: <waterwiki.net/images/e/ee/Applying_HRBA_To_Development_Programming.pdf> at 8.

349 Maarten Immink & Margaret Vidar, "Monitoring the Human Right to Adequate Food at Country Level" in Gudmundur Alfredsson et al, eds, *International Human Rights Monitoring Mechanisms*, 2nd ed, (Leiden, Netherlands: Brill | Nijhoff, 2009) at 322.

350 Slade, Bauen & Gross, *supra* note 196 at 103.

351 *Ibid.*

352 *The Global Bioenergy Partnership Sustainability Indicators for Bioenergy* (2011), online: Global Bioenergy Partnership www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf. See also Yoshiko Naiki, "Trade and Bioenergy: Explaining and Assessing the Regime Complex for Sustainable Bioenergy" (2016) 27:1 Eur J Intl L 129 at 142–44.

353 UNHRC, *Report of the Office of the United Nations High Commissioner for Human Rights on the relationship between climate change and human rights*, 15 January 2009, UNHRCOR, 10th Sess, UN Doc A/HRC/10/61, online: <www.ohchr.org/Documents/Press/AnalyticalStudy.pdf>; Gromilova, *supra* note 296 at 91.

354 For example, the International Council on Human Rights Policy has also advocated application of an HRBA in the context of climate change policymaking; International Council on Human Rights Policy, *Climate Change and Human Rights: A Rough Guide* 9 (2008), online: <www.ohchr.org/Documents/Issues/ClimateChange/Submissions/136_report.pdf>.

355 Center for International Environmental Law, *Human Rights and Climate Change: Practice Steps for Implementation* (2009), online: <www.ciel.org/Publications/CCandHRE_Feb09.pdf> at 1–32.

rights subsidiary body comprised of human rights and development experts. This body could be tasked, *inter alia*, with developing HRBA architecture, advising the COP on relevant human rights standards and reporting on best national practices.[356] Alternatively, the most appropriate current institutions for operationalizing the HRBA process under the Paris Agreement would be its Subsidiary Body for Implementation (SBI) and Subsidiary Body for Scientific and Technological Advice (SBSTA). The SBI was established under the UNFCCC to assist the parties "in the assessment and review of the effective implementation of the Convention."[357] The SBSTA was established in the UNFCCC "to provide the Conference of the Parties and, as appropriate, its other subsidiary bodies with timely information and advice on scientific and technological matters relating to the Convention,[358] including "scientific assessments on the effects of measures taken in the implementation of the Convention."[359] The SBI has been designated in both the Kyoto Protocol and the Paris Agreement to fulfill the same functions,[360] as has the SBSTA.[361]

At COP17, the parties to the UNFCCC established a "forum on the impact of the implementation of response measures," which was mandated to meet twice annually under the rubric of the SBI and SBSTA.[362] The forum is tasked, *inter alia*, with assessment of the impacts of climate response measures and engendering cooperation on response strategies.[363] At COP21 in Paris, the parties decided to extend the mandate of the forum, and to strengthen it, by, *inter alia*, enhancing the capacity of the parties to deal with the impact of implementation of response measures and establishment of ad hoc technical expert groups.[364]

The forum would be an appropriate body to conduct an HRBA on behalf of the parties to the Paris Agreement or the Kyoto Protocol. It could establish an ad hoc technical expert group with expertise in both the technological aspects of geoengineering and in the field of human rights law.[365] As indicated above, it could also seek assistance from the OHCHR and other human rights bodies in terms of human rights considerations.[366]

To further strengthen accountability, the parties could require that the transparency mechanisms of the Paris Agreement,[367] comprised of national communications and biennial reports, contain a section on how human rights are being integrated into climate change response measures. Non-state actors could also be invited to supplement these reports in this context, reflecting the Universal Periodic Review process under the auspices of the UNHRC.[368] Moreover, the parties to the agreement could also consider establishing a formal grievance mechanism to provide another avenue for potentially affected parties to seek accountability. Models for such a mechanism might include the International Finance Corporation's Compliance Advisor Ombudsman or the UNDP's Compliance Review and Grievance Process.[369]

As Stephen M. Gardiner concludes, "To exert control over the planetary system is to determine the basic life prospects of humans within that system, including the parameters against which they pursue their conceptions of the good, generate their ideals, and even conceive of their identities."[370] While one should not overemphasize the potential effectiveness of an HRBA process in the context of climate geoengineering, it might ultimately imbue the world's most vulnerable people with some measure of agency in what would constitute a truly momentous decision.

356 Naomi Roht-Arriaza, "Human Rights in the Climate Change Regime" (2010) 1:2 J Hum Rts & Envt 211 at 232.

357 UNFCCC, *supra* note 2, art 10(1).

358 *Ibid*, art 9(1).

359 *Ibid*, art 9(2)(b).

360 Kyoto Protocol, *supra* note 3 at art 15(1); Paris Agreement, *supra* note 7 at art 18(1).

361 *Ibid.*

362 UNFCCC, "Forum on the impact of the implementation of response measures", online: <unfccc.int/cooperation_support/response_measures/items/7418.php>.

363 *Ibid.*

364 UNFCCC, *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015*, 29 January 2016, UN Doc FCCC/CP/2015/10/Add.2, Dec 11/CP.21, *Forum and Work Programme on the Impact of Implementation of Response Measures*, online: <unfccc.int/resource/docs/2015/cop21/eng/10a02.pdf>.

365 Center for International Environmental Law, *supra* note 355 at 29.

366 See note 354 and accompanying text. Another alternative would be to establish an expert group on human rights. While such groups are composed of experts acting in their personal capacity and don't have the same status as the official Subsidiary Bodies of the UNFCCC, they could provide the parties with some guidance, as does the least developed countries (LDCs) Expert Group, which supports developing countries in the preparation of their National Adaptation Programs of Action. UNFCCC, LDC Expert Group, online: <unfccc.int/adaptation/groups_committees/ldc_expert_group/items/4727.php>.

367 Paris Agreement, *supra* note 7, art 13(4).

368 Mary Robinson Foundation, *supra* note 1 at 7.

369 Center for International Environmental Law & CARE International, *Climate Change: Tackling the Greatest Human Rights Challenge of Our Time* (2015), online: <www.ciel.org/reports/climate-change-tackling-the-greatest-human-rights-challenge-of-our-time-careciel-february-2015/> at 10.

370 Stephen M Gardiner, "The Desperation Argument for Geoengineering" (2013) 46:1 Political Science & Politics 28 at 29.

Challenges to Implementing an HRBA in the Context of Climate Geoengineering

EXTRATERRITORIAL APPLICATION OF HUMAN RIGHTS

A state that would make the decision, for example, to allocate land for BECCS' feedstock or to deploy an SRM option would have an obligation to respect, protect and fulfill the human rights of its nationals.[371] However, it is quite likely that deployment of many climate geoengineering options would have ramifications well beyond the borders of any country. Thus, a pertinent question is whether a state's obligations under international human rights law extend to individuals that are not within a state's territory or effective control. This is usually referred to as the question of "extraterritorial" application of human rights principles.[372] This is obviously an extremely important question given the large number of circumstances under which deployment of geoengineering might have transboundary impacts, with the duty-bearers and rights-holders potentially separated by thousands of miles.

As Marc Limon observed, "existing human rights law is primarily concerned with how a government treats its own citizens and others within its territory or under its jurisdiction."[373] This is the "vertical" duty of a state in terms of human rights.[374] Imposition of so-called "diagonal" or extraterritorial duties is a far closer case from a legal perspective.[375] However, a reasonable case can be made for this proposition and, thus, by extension, an application of a human rights-based approach extraterritorially.

It is pertinent to initially examine relevant provisions of key human rights instruments. The UDHR contains no language limiting its jurisdiction to protection of the human rights of nationals.[376] In fact, there is a suggestion of extraterritorial scope, as it provides that "no State, group or person" has a right to contravene rights outlined in the declaration.[377] The ICESCR also contains no jurisdictional limits and, in fact, obliges states to take steps "individually and *through international assistance and co-operation*" to achieve full realization of the rights contained in the treaty.[378] The Committee on Economic, Social and Cultural Rights, which monitors implementation of the ICESCR, has recognized a number of obligations with extraterritorial effect. These include respecting the right to enjoyment of the right to food in other countries by refraining from the imposition of food embargoes and operationalizing the requirement of assistance by providing food aid when required,[379] as well as international cooperation to achieve the full realization of the right to health.[380] The American Declaration of the Rights and Duties of Man similarly provides that "[t]he *international protection of the rights of man* should be the principle guide of an evolving American law."[381] The Committee on the Rights of the Child has argued that parties to human rights conventions have obligations both to implement them within their jurisdictions as well as contribute to global implementation through international cooperation, although it does not specify the nature of this cooperation.[382]

On the other hand, the ICCPR could be construed as precluding extraterritorial application of its mandates, providing that state parties are to "respect and to ensure to all individuals *within its territory and subject to its jurisdiction* the rights recognized in the present Covenant."[383] However, some commentators have suggested that this provision could be read disjunctively, with parties thus being required to respect the rights set forth in the covenant without territorial limitation, while preventing and redressing rights violations within their jurisdictions.[384]

Several provisions of the United Nations Charter also support the proposition that states have extraterritorial

371 See notes 245–248 and accompanying text.

372 Edward Cameron & Marc Limon, "Restoring the Climate by Realizing Rights: The Role of the International Human Rights System" (2012) 21 RECEIL 204 at 212.

373 Marc Limon, "Human Rights and Climate Change: Constructing a Case for Political Action" (2009) 33 Harv Envtl L Rev 439 at 458. See also Sigrun I Skogly, "Extra-National Obligations Towards Economic and Social Rights" (2002) International Council on Human Rights Policy, Council Meeting, Background Paper, online: <www.ichrp.org/files/papers/93/108_-_Extra-national_Obligations_-_Towards_Economic_and_Social_Rights_Skogly__Sigrun_I.__2002.pdf> at 1.

374 McInerney-Lankford, *supra* note 233 at 40.

375 *Ibid.*

376 Beth van Schaack, "The United States' Position on the Extraterritorial Application of Human Rights Obligations: Now is the Time for Change" (2014) 90 Intl L Stud 20 at 25.

377 *UDHR*, *supra* note 235, art 30.

378 *ICESCR*, *supra* note 220, art 2(1) [emphasis added].

379 General Comment 12, *supra* note 255 at paras 36–42.

380 General Comment 14, *supra* note 262 at para 39.

381 *American Declaration of the Rights and Duties of Man*, *supra* note 227 at Preamble [emphasis added].

382 UN Committee on the Rights of the Child, General Comment No 5 (2003): General measures of implementation of the Convention on the Rights of the Child, 27 November 2003, 34th Sess, UN Doc CRC/GC/2003/5 at para 7, online: <www2.ohchr.org/english/bodies/crc/docs/GC5_en.doc>.

383 *ICCPR*, *supra* note 219, art 2(1) [emphasis added].

384 Rolf Künnemann, "Extraterritorial Application of the International Covenant on Economic, Social and Cultural Rights" in Fons Coomans & Menno T Kamminga, eds, *Extraterritorial Application of Human Rights Treaties* (Cambridge, UK: Intersentia, 2004) at 201, 222–229; van Schaack, *supra* note 376 at 28–29.

human rights obligations. Article 55 of the Charter provides for UN promotion of "universal respect for, and observance of, human rights,[385] and article 56 mandates that member states "take *joint* and separate action" to achieve this purpose.[386]

In 2011, 40 international law experts from around the world adopted the Maastricht Principles on Extraterritorial Obligations in the Area of Economic, Social and Political Rights.[387] The principles were intended to serve as a clarification of extraterritorial legal obligations in terms of existing international law. The principles provide, *inter alia*, that all states "have obligations to respect, protect and fulfill human rights...both within their territories and extraterritorially,"[388] The principles further conclude that a state has human rights obligations not only in situations over which it exerts "authority or effective control,"[389] but also in "situations over which State acts or omissions bring about foreseeable effects on the enjoyment of economic, social and cultural rights, whether inside or outside its territory,"[390] or "situations in which the State, acting separately or jointly...is in a position to exercise decisive influence or to take measures to realize economic, social and cultural rights extraterritorially.[391]

Assuming that extraterritorial human rights obligations can be established, how would we construe their scope in the context of climate geoengineering? A reasonable approach is to examine the scope of the duties to respect, protect and fulfill at the international level.[392] The duty to respect in an extraterritorial context requires that states "avoid measures that hinder or prevent the enjoyment of…rights in another state."[393] Thus, states deploying geoengineering technologies would be required to avoid options that might undermine the exercise of human rights in other countries, such as approaches that might reduce food production or deplete the ozone layer, potentially imperilling the right to health in non-deploying states.

The extraterritorial duty to protect has two components. First, states must take into account human rights in terms of negotiation and implementation of treaties or when entering into multilateral or bilateral obligations.[394] Second, states must take measures to ensure that non-state entities within their jurisdictions do not interfere with the enjoyment of rights in other countries.[395] Thus, in the context of climate geoengineering, this would require states to take into account human rights obligations in treaty regimes of which they are parties, as well as in multilateral or bilateral collaborations. This should include ensuring an inclusive process that engenders full participation by all potentially affected parties and affords them meaningful opportunities for consultation.

The duty to fulfill is controversial in the international context because of its emphasis on the need to take positive state action in other nations.[396] However, there is increasing recognition of the international human rights obligation to fulfill as a secondary or subsidiary duty should measures taken to respect or protect prove insufficient.[397]

SHOULD CLIMATE GEOENGINEERING AND HUMAN RIGHTS BE VIEWED FROM A COMPARATIVE HUMAN RIGHTS PERSPECTIVE?

Some commentators have contended that deployment of climate geoengineering options may ultimately prove to be compelling despite their risks because the spectre of steadily rising emissions and associated climatic impacts could constitute a more imposing global risk.[398]

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385 *Charter of the United Nations*, 26 June 1945, Can TS 1945 No 7, art 55(c), online: <www.un.org/en/sections/un-charter/un-charter-full-text/index.html>.

386 *Ibid*, art 56. See also *ibid*, art 1(3). Among the purposes of the United Nations are "to achieve international cooperation...in promoting and encouraging respect for human rights...."

387 Maastricht Principles on Extraterritorial Obligations in the Area of Economic, Social and Political Rights, ETOs for Human Rights Beyond Borders (2013), online: <www.etoconsortium.org/nc/en/main-navigation/library/maastricht-principles/?tx_drblob_pi1%5BdownloadUid%5D=23>.

388 *Ibid*, s I.3.

389 *Ibid*, s II.9(a).

390 *Ibid*, s II.9(b).

391 *Ibid*, s II.9(c).

392 Emily A Mok, "International Assistance and Cooperation for Access to Essential Medicines" (2010) 12 Health & Hum Rts 73 at 76, online: <scholarship.law.georgetown.edu/cgi/viewcontent.cgi?article=1606&context=facpub>.

393 Sigrun Skogly, *Beyond National Borders: States' Human Rights Obligations in International Cooperation* (Cambridge, UK: Intersentia, 2006) 66. See also Limon, *supra* note 373 at 454.

394 M Carmona, "The Obligations of 'International Assistance and Cooperation' Under the International Covenant on Economic, Social and Cultural Rights: A Possible Entry Point to a Human Rights Based Approach to Millennium Development Goal 8" (2009) 13:1 Intl J Hum Rts 86 at 91; Mark Gibney, "Responsibilities for Protecting Human Rights" (3 February 2008) 1:3 Global-e, online: <https://global-ejournal.org/2008/02/15/gibney/>.

395 Carmona, *supra* note 394 at 91.

396 Mok, *supra* note 392 at 76.

397 Skogly, *supra* note 393 at 71; Wouter Vandehoule, *Is There a Legal Obligation to Cooperate Internationally for Development*, Report to General Day of Discussion, Convention on the Rights of the Child (July 27, 2007), online: <www.crin.org/en/docs/Vandenhole%20International%20Cooperation.pdf>.

398 Bullis, *supra* note 139; Owen, *supra* note 16 at 214.

By extension, it might be argued that the human rights violations associated with climate change under current trajectories might "trump" those of climate geoengineering.

David Morrow and Toby Svoboda have developed an analytical framework, premised on principles of justice, that can help guide societal choices between "non-ideal" policy options. These are choices that must be made under conditions of "imperfectly just circumstances."[399] They argue that climate geoengineering and current trends in climate change constitute a non-ideal policy environment, with society's "less than ideal response to the threat of climate change" leading many to advocate for climate geoengineering, despite the risks that it could also impose.[400] Geoengineering, Svoboda argues in another piece, "may do better than emissions mitigation or adaptation alone when it comes to serving both overall welfare and incomplete fairness."[401]

However, Morrow and Svoboda also propose two criteria that must be met to justify a "non-ideal" policy option such as geoengineering: "a proportionality criterion," which "compares the *prima facie* wrongs that a non-ideal policy inflicts with the injustice that it alleviates;" and a "comparative criterion," which "compares a proposed non-ideal policy with other politically feasible alternatives."[402] The HRBA developed in this report could play an important role in conducting such an analysis. It could help society to compare the human rights implications of the impacts of climate change and geoengineering as a way of operationalizing the concept of "*prima facie* wrongs." Moreover, it would provide one set of metrics, to be utilized in conjunction with others in the realms of economics and environmental considerations, to compare geoengineering with policy alternatives. As indicated above, this might include alternatives such as aggressive efforts to reduce black carbon as a mechanism to slow down rates of warming and give us more "space" to decarbonize the economy,[403] as well as efforts to substantially accelerate the path to transformation of our economy to one based on "winds, water and sunlight" by 2050.[404] As Gardiner has observed, even in the face of frightening climatic scenarios, we should not assume that climate geoengineering is the "lesser evil" until we have thoroughly vetted all mitigation and adaptation options.[405]

CONCLUSIONS

The Paris Agreement provides a framework for taking human rights into account in responding to climate change. This paper has sought to outline a framework for operationalizing this broad mandate in the context of climate geoengineering.

It is hoped that this framework might also prove helpful in assessing the human rights implications of mitigation and adaptation options. To date, consideration of the human rights implications of adaptation responses has been "peripheral."[406] Some adaptation strategies, such as forced assimilation of indigenous peoples for compelled migration, may raise severe human rights questions that should be addressed by the parties to the Paris Agreement.[407] In the context of adaptation responses, an HRBA could also be a salutary mechanism to avoid so-called "negative lock-ins," that is, approaches that undermine the ability of the system to respond to larger subsequent impacts. The focus in human rights analyses on the root causes of vulnerability would help to avoid sclerotic adaptive responses.[408] Similar concerns have been raised in the context of mitigation responses, including the

399 David Morrow & Toby Svoboda, "Geoengineering and Non-Ideal Theory" (2016) 30:1 Public Aff Q 83 at 84.

400 *Ibid* at 86.

401 Toby Svoboda, "Aerosol Geoengineering Deployment and Fairness" (2016) 25 Envtl Values 51 at 65.

402 Morrow & Svoboda, *supra* note 399 at 86.

403 See notes 337–342 and accompanying text.

404 See Mark Z Jacobson & Mark A Delucchi, "Providing All Global Energy with Wind, Water, and Solar Power, Part I: Technologies, Energy Resources, Quantities and Areas of Infrastructure and Materials" (2011) 39 Energy Pol'y 1154 at 1169; Mark A Delucchi & Mark Z Jacobson, "Providing All Global Energy with Wind, Water, and Solar Power, Part II: Reliability, System and Transmission Costs and Policies" (2011) 39 Energy Pol'y 1170 to 1190. For a critical review of such proposals, see Peter J Loftus et al, "A Critical Review of Global Decarbonization Scenarios: What Do They Tell Us About Feasibility?" (2015) 6:1 Climate Change 93 at 112.

405 Stephen M Gardiner, "Is 'Arming the Future' with Geoengineering Really the Lesser Evil?" in Stephen M Gardiner et al, eds, *Climate Ethics: Essential Readings* (Don Mills: Oxford University Press, 2010) 284 at 292.

406 Australia, Human Rights and Equal Opportunity Commission, "Human Rights and Climate Change" (2008), online: <https://www.humanrights.gov.au/papers-human-rights-and-climate-change-background-paper> at 14.

407 John Crowley, "Climate Change, Climate Knowledge and Human Rights" (2011), online: <www.ohchr.org/Documents/Issues/ClimateChange/Seminar2012/JohnCrowley_UNESCO_23Feb.2012.pdf> at 3.

408 Fisher, *supra* note 298 at 13.

Clean Development Mechanism of the Kyoto Protocol[409] and efforts to reduce deforestation (REDD+).[410]

The Paris Agreement may ultimately be viewed as a major breakthrough in the field of climate policy making, as well as a powerful force for defending the human rights of the most vulnerable in our society from environmental change. The emerging field of climate geoengineering affords us an opportunity to develop a framework to make human rights more than merely an aspiration in the context of climate policy making.

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409 International Bar Association, *supra* note 190 at 50; Roht-Arriaza, *supra* note 356 at 215, 216; MISEREOR, CIDSE & Carbon Market Watch, *Human Rights Implications of Climate Mitigation Actions*, 2nd ed, (May 2016), online: <carbonmarketwatch.org/wp-content/uploads/2016/05/NC-HUMAN-RIGHTS-IMPLICATIONS-OF-CLIMATE-CHANGE-MITIGATION-ACTIONS-VERSION-02-MAY-2016-OK-WEB-spread-page-.pdf> at 17-18.

410 Kirsty Gover, "REDD+, Tenure and Indigenous Property: The Promise and Peril of a 'Human Rights-Based Approach" in Christina Voigt, ed, *Research Handbook on REDD+ and International Law* (Cheltenham, UK: Edward Elgar Publishing, 2016) at 249–283; Annalisa Savaresi, "The Role of REDD in the Harmonisation of Overlapping International Obligations" in Erkki Hollo, Kati Kulovesi & Michael Mehling, eds, *Climate Change and the Law* (New York, NY: Springer, 2013) 391 at 414.

ABOUT CIGI

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