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ARTICLE

Towards a Non-Use Regime on Solar Geoengineering: Lessons from International Law and Governance

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Abstract

In recent years, some scientists have called for research into and potential development of 'solar geoengineering' technologies as an option to counter global warming. Solar geoengineering refers to a set of speculative techniques to reflect some incoming sunlight back into space, for example, by continuously spraying reflective sulphur aerosols into the stratosphere over several generations. Because of the significant ecological, social, and political risks posed by such technologies, many scholars and civil society organizations have urged governments to take action to prohibit the development and deployment of solar geoengineering techniques. In this article we take such calls for a prohibitory or a non-use regime on solar geoengineering as a starting point to examine existing international law and governance precedents that could guide the development of such a regime. The precedents we examine include international prohibitory and restrictive regimes that impose bans or restrictions on chemical weapons, biological weapons, weather modification technologies, anti-personnel landmines, substances that deplete the ozone layer, trade in hazardous wastes, deep seabed mining, and mining in Antarctica. We also assess emerging norms and soft law in anticipatory governance of novel technologies, such as human cloning and gene editing. While there is no blueprint for a solar geoengineering non-use regime in international law, our analysis points to numerous specific elements on which governments could draw to constrain or impose an outright prohibition on the development of technologies for solar geoengineering, should they opt to do so.

Keywords: Solar geoengineering; Climate change; Prohibitory regimes; Solar radiation modification; Non-use agreement

1. Introduction

Recent years have seen a surge of proposals from experts and science institutions, particularly in the United States (US), to explore the potential of 'solar geoengineering' technologies to counter the adverse consequences of climate change.[1] Solar geoengineering, also called solar radiation modification (SRM), aims to artificially intervene in the climate system by reflecting a part of incoming sunlight back out into space, thereby inducing a cooling effect. Several solar geoengineering technologies have been proposed, ranging from the brightening of marine clouds to the placement of mirrors in outer space. The most widely discussed technology is the injection of reflective sulphur aerosols into the stratosphere from special aircraft to deflect some incoming sunlight.[2]

Solar geoengineering technologies are speculative and highly controversial, and no such technologies have yet been developed or deployed.[3] While advocates of more research into solar engineering note the potential for a rapid cooling effect through SRM,[4] others point to the uncertain, unevenly distributed and potentially unknowable risks and harm from any future deployment of solar geoengineering.[5] These risks and harms include dangerous consequences for the biophysical environment, including

[1] United States National Academies of Sciences, Engineering, and Medicine, *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (National Academies Press, 2021).

[2] Ibid.

[3] Our focus here is on solar radiation modification (SRM). We do not include carbon dioxide removal (CDR) in our discussion. These is a distinct set of techniques from SRM in their focus on removing accumulated carbon in the atmosphere rather than manipulating incoming sunlight, and pose distinct governance challenges; see, e.g., K. Brent et al., 'International Law Poses Problems for Negative Emissions Research' (2018) 8(6) *Nature Climate Change*, pp. 451–3.

[4] On a potential cooling effect of SRM see the discussion in the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report, Working Group I, Section 4.6.3.3 'Climate Response to Solar Radiation Modification', in J.-Y. Lee et al., 'Future Global Climate: Scenario-based Projections and Near-Term Information', in V.P. Masson-Delmotte et al. (eds), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press), pp. 553–672, at 624–29. Elsewhere in this IPCC 6th Assessment Report, including in the contributions of Working Groups II and III, an array of potential risks and harms associated with SRM are also assessed. The entire report is available at: https://www.ipcc.ch/assessment-report/ar6.

[5] Academic literature on solar geoengineering covers a wide range of ecological, ethical, political, and security concerns; see, e.g., C. Hamilton, *Earthmasters: The Dawn of the Age of Climate Engineering* (Yale University Press, 2013); J.C. Stephens et al., 'Toward Dangerous US Unilateralism on Solar Geoengineering' (2023) 32(1) *Environmental Politics*, pp. 171–3; J.A. Flegal & A. Gupta, 'Evoking Equity as a Rationale for Solar Geoengineering Research? Scrutinizing Emerging Expert Visions of Equity' (2018) 18(1) *International Environmental Agreements: Politics, Law and Economics*, pp. 45–61; C.H. Trisos et al., 'Potentially Dangerous Consequences for Biodiversity of Solar Geoengineering Implementation and Termination' (2018) 2 *Nature, Ecology and Evolution*, pp. 475–82; F. Biermann & I. Möller, 'Rich Man's Solution? Climate Engineering Discourses and the Marginalization of the Global South' (2019) 19(2) *International Environmental Agreements: Politics, Law and Economics*, pp. 151–67; C. McKinnon, 'Sleepwalking into Lock-in? Avoiding Wrongs to

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biodiversity, the ozone layer, and regional climate,[6] as well as for social justice and political stability.[7] In addition, there is concern that even contemplating such speculative future options may itself divert attention from the urgent task of prioritizing deep emission cuts now.[8]

In response to these concerns, a global group of over 490 academics, supported by over 1,900 civil society organizations, is calling upon governments and the United Nations (UN) to agree on an International Non-Use Agreement on Solar Geoengineering.[9] While this proposal has received ample media attention and generated much debate in expert communities,[10] the possible structure and legal design of a restrictive or prohibitory regime on solar geoengineering has not yet been examined in detail by international lawyers and governance scholars. Examining these aspects is our aim in this article.[11]

Specifically, we seek to draw lessons from other areas of international law and governance where global risks and potential harm have been regulated through prohibitory or restrictive regimes. This approach allows us to examine precedents and distil existing legal approaches that could be relevant for a future non-use agreement on solar geoengineering, should governments opt to negotiate such a regime in the future.

Future People in the Governance of Solar Radiation Management Research' (2019) 28(3) *Environmental Politics*, pp. 441–59.

6 Trisos et al., n. 5 above; S. Tilmes, R. Müller & R. Salawitch, 'The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes' (2008) 320(5880) *Science*, pp. 1201–4; G.C. Hegerl & S. Solomon, 'Risks of Climate Engineering' (2009) 325(5943) *Science*, pp. 955–6; A.C. Jones et al., 'Regional Climate Impacts of Stabilizing Global Warming at 1.5 K Using Solar Geoengineering' (2018) 6(2) *Earth's Future*, pp. 230–51.

7 E.g., J.C. Stephens & K. Surprise, 'The Hidden Injustices of Advancing Solar Geoengineering Research' (2020) 3 *Global Sustainability*, e2; J.C. Stephens et al., 'The Dangers of Mainstreaming Solar Geoengineering: A Critique of the National Academies Report' (2023) 32(1) *Environmental Politics*, pp. 157–66.

8 D. McLaren, 'Mitigation Deterrence and the "Moral Hazard" of Solar Radiation Management' (2016) 4(12) *Earth's Future*, pp. 596–602; K. Ellison, 'Why Climate Change Sceptics Are Backing Geoengineering', *Wired*, 28 Mar. 2008, available at: https://www.wired.com/story/why-climate-change-skeptics-are-backing-geoengineering.

9 See F. Biermann et al., 'Solar Geoengineering: The Case for an International Non-Use Agreement' (2022) 13(3) *Wiley Interdisciplinary Reviews: Climate Change*, pp. 1–8. The list of over 490 academic signatories and numerous civil society supporters is available at: https://www.solargeoeng.org.

10 For an early example of media engagement with the proposal calling for a non-use agreement, see D. Vetter, 'Solar Geoengineering: Why Bill Gates Wants It but These Experts Want To Stop It', *Forbes*, 22 Jan. 2022, available at: https://www.forbes.com/sites/davidrvetter/2022/01/20/solar-geoengineering-why-bill-gates-wants-it-but-these-experts-want-to-stop-it. See, more generally, B. Clark, 'How To Argue about Solar Geoengineering' (2023) 40(3) *Journal of Applied Philosophy*, pp. 505–20.

11 We take this 'non-use' proposal (elaborated in Biermann et al., n. 9 above) as our general point of departure to explore what a potential restrictive regime on solar geoengineering could look like. However, our aim is not to develop a blueprint for how to realize the specifics of this proposal. Instead, we view this call for 'non-use' of solar geoengineering as an invitation to examine existing prohibitory and restrictive regimes in other areas of international governance, in order to learn lessons for restrictive solar geoengineering governance. For further details on the specific non-use proposal of Biermann and co-authors, including how its proponents respond to arguments and counter-arguments about risks and benefits of solar geoengineering, see, e.g., briefing notes available at: https://www.solargeoeng.org/resources/briefing-notes.

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The existing prohibitory or restrictive regimes that we examine here cover issues of international security, human rights, and the environment. These include international regimes addressing the non-proliferation of nuclear weapons, as well as prohibitions or restrictions on, inter alia, anti-personnel land mines, chemical and biological weapons, the military or other hostile use of environmental modification techniques, emissions of substances that deplete the stratospheric ozone layer, mining in Antarctica, and the transboundary movements of hazardous wastes. We also include regimes that prohibit violations of fundamental human rights, as well as emerging or proposed national and transnational restrictive rules on human cloning and deep seabed mining.

Although the nature of the issues addressed by each of these regimes varies and is distinct from that of solar geoengineering, essential elements of regime design – such as *what* is subject to prohibition, and *how*, along with systems of monitoring and compliance control – may be similar. This enables us to distil valuable lessons and approaches from examination of these existing regimes. Although our primary focus is on international prohibitory or restrictive regimes, we also draw on restrictive governance approaches from national law, non-binding decisions, and the broader literature on international law and solar geoengineering, where relevant.[12]

We proceed as follows. Section 2 briefly discusses the general nature, dynamics, and emergence of prohibitory and restrictive regimes, and associated underlying principles of international law and technology regulation. In Section 3, we analyze in detail key elements of international prohibitory and restrictive regimes, drawing also on relevant other sources, with a view to assessing the spectrum of options for the design of a future non-use regime on solar geoengineering. Section 4 concludes our analysis.

2. International Legal Precedents

Prohibition is an important objective and function of international law. Several international legal regimes, from human rights-based to environment and technology regimes, have evolved to prohibit certain acts of states, and sometimes also acts of non-state actors.[13] Generally speaking, these regimes consist of binding treaty norms, general principles of international law, customary norms, peremptory norms, or a mix of these.[14] They either prohibit something outright or restrict certain activities, such as research and development, or trade related to a specific activity.

[12] E.g., K.N. Scott, 'International Law in the Anthropocene: Responding to the Geoengineering Challenge' (2012) 34(2) *Michigan Journal of International Law*, pp. 309–58; N. Craik, 'International EIA Law and Geoengineering: Do Emerging Technologies Require Special Rules?' (2015) 5(2) *Climate Law*, pp. 111–41; K. Brent, J. McGee & J. McDonald, 'The Governance of Geoengineering: An Emerging Challenge for International and Domestic Legal Systems?' (2015) 24(1) *Journal of Law, Information and Science*, pp. 1–33.

[13] E. Nadelmann, 'Global Prohibition Regimes: The Evolution of Norms in International Society' (1990) 44(4) *International Organization*, pp. 479–526. See also, generally, G.H. von Wright, *Norm and Action* (Routledge & Kegan Paul, 1963).

[14] See Art. 38 of the Statute of the International Court of Justice, San Francisco, CA (US), 26 June 1945, in force 24 Oct. 1945, available at: http://www.icj-cij.org/en/statute. See further, e.g., J. Klabbers, *International Law* (Cambridge University Press, 3rd edn, 2021).

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2.1. Specific Challenges and General Principles

Numerous issue areas are covered by prohibitory regimes. One key category relates to human rights, namely, the prohibition against torture,[15] which is considered a peremptory norm in international law from which no derogation is allowed.[16] Other human rights-based regimes are those related to the prohibition against the use of armed force and the prohibition against slavery.[17] In the environmental domain, examples are the prohibition of mining in Antarctica,[18] and the prohibition of military or hostile use of environmental modification techniques.[19] Another example, though not strictly prohibitory, is contained within the United Nations Convention on the Law of the Sea (UNCLOS),[20] which provides that governments 'shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control … which may cause significant and harmful changes thereto'.[21] Some prohibition regimes related to the environment, such as the Environmental Protection Protocol to the Antarctic Treaty regime, are based on principles of international environmental law, such as prevention and precaution, which aim to anticipate and govern risk and potential unintended consequences of certain activities.[22]

Another category of prohibitory regimes concerns certain types of weapon, including biological or chemical weapons, and notably nuclear weapons, which are subject to specific prohibitory regimes but are also based on customary international law principles, such as no (transboundary) harm. For example, in the case of nuclear weapons, the International Court of Justice (ICJ) confirmed the application of this no-harm

[15] E.g., Art. 5 of the Universal Declaration of Human Rights, Paris (France), 10 Dec. 1948, adopted by United Nations General Assembly (UNGA) Resolution 217A (III), available at: https://www.un.org/en/about-us/universal-declaration-of-human-rights; Art. 7 of the International Covenant on Civil and Political Rights (ICCPR), New York, NY (US), 16 Dec. 1966, in force 23 Mar. 1976, available at: https://www.ohchr.org/sites/default/files/ccpr.pdf; Art. 5 of the African Charter on Human and Peoples' Rights, Nairobi (Kenya), 27 June 1981, in force 21 Oct. 1986, available at: https://au.int/en/treaties/african-charter-human-and-peoples-rights.

[16] M.Y. Bhat, 'Menace of Torture: Prohibition in International Law' (2006) 67(3) *The Indian Journal of Political Science*, pp. 553–72.

[17] See, respectively, J. Westra, *International Law and the Use of Armed Force: The UN Charter and the Major Powers* (Routledge, 2007); K. Bales & P. Robbins, '"No One Shall be Held in Slavery or Servitude": A Critical Analysis of International Slavery Agreements and Concepts of Slavery' (2001) 2(2) *Human Rights Review*, pp. 18–45.

[18] Art. 3 of the Protocol on Environmental Protection to the Antarctic Treaty, Madrid (Spain), 4 Oct. 1991, in force 14 Jan. 1998, available at: https://www.antarctica.gov.au/about-antarctica/law-and-treaty/the-madrid-protocol/#:~:text=The%20Protocol%3A,prohibits%20mining%20indefinitely. See, e.g., D. Vidas, 'The Protocol on Environmental Protection to the Antarctic Treaty: A Ten-Year Review' (2002) *Yearbook of International Cooperation on Environment and Development 2002–03*, pp. 51–60.

[19] E.g., A. Westing, 'Environmental Warfare' (1985) 15(4) *Environmental Law*, pp. 645–66.

[20] Montego Bay (Jamaica), 10 Dec. 1982, in force 16 Nov. 1994, available at: http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm.

[21] Ibid., Art. 196(1). See P. Verlaan 'Geo-engineering, the Law of the Sea and Climate Change' (2009) 3(4) *Carbon and Climate Law Review*, pp. 446–58, at 450 (noting that '[t]he mandatory "shall" is seldom qualified in the [UNCLOS], and almost never in the environmental provisions. The [UNCLOS] is remarkable for the mandatory unqualified and usually specific nature of the obligations placed upon States in general and its environmental provisions in particular': ibid., p. 450).

[22] N. 18 above.

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principle by stating that '[t]he existence of the general obligation of States to ensure that activities within their jurisdiction and control respect the environment of other States or of areas beyond national control is now part of the corpus of international law relating to the environment'.[23] This ruling, evoking the application of the no-harm principle, applies to all states, even those that are not party to any specific treaty that prohibits the use of nuclear weapons, such as the 2017 Treaty on the Prohibition of Nuclear Weapons.[24]

2.2. Prohibitions as Moral and Ethical Judgements

Most prohibitory norms have in common that:

> [they] strictly circumscribe the conditions under which states can take part in and authorize [potentially harmful] activities and proscribe all involvement by non-state actors. Those who refuse or do not conform are labelled as deviants and condemned not just by states but by most communities and individuals as well.[25]

Prohibition regimes are thus, by definition, associated with moral and ethical judgements about specific practices, behaviours, or substances. They are, in other words, one of the ways to embed values in governance and distinguish appropriate from inappropriate behaviour.[26] As a result of their moral and ethical underpinnings, these regimes aim to delegitimize something, while providing states with the morally and ethically undergirded legal means to reject what they deem to be inappropriate, and to invoke appropriate coercive measures to sanction non-compliance with a prohibition.[27]

2.3. Reactive versus Proactive Prohibitions

Prohibitory regimes can be reactive, proactive, or a mix of both. Reactive regimes try to mitigate recognized types of harm that have occurred or are occurring, or they aim to prevent future harm from known hazardous substances, activities, or technologies. The nuclear non-proliferation and disarmament regime, as articulated in the 1968 Treaty

[23] *Legality of the Threat or Use of Nuclear Weapons*, Advisory Opinion, 8 July 1996, *ICJ Reports* (1996), p. 226, para. 29. See also *Iron Rhine Arbitration* (*Belgium* v. *Netherlands*) Award, 24 May 2005, XXVII *Reports of International Arbitral Awards* (2005), p. 35, para. 222; *Pulp Mills on the River Uruguay* (*Argentina* v. *Uruguay*) Judgment, 20 Apr. 2010, *ICJ Reports* (2010), p. 14, para. 101. On the nature and theory of customary international law see, among others, B. Lepard, *Customary International Law: A New Theory with Practical Applications* (Cambridge University Press, 2010).

[24] New York, NY (US), 7 July 2017, in force 22 Jan. 2021, available at: https://disarmament.unoda.org/wmd/nuclear/tpnw.

[25] Nadelmann, n. 13 above, p. 479.

[26] J. March & J.P. Olsen, 'The Institutional Dynamics of International Political Orders' (1998) 52(4) *International Organization*, pp. 943–69; M. Finnemore, *National Interests in International Society* (Cornell University Press, 1996); K. O'Neill, J. Balsiger & S.D. VanDeveer, 'Actors, Norms, and Impact: Recent International Cooperation Theory and the Influence of the Agent-structure Debate' (2004) 7 *Annual Review of Political Science*, pp. 149–75.

[27] R. Gibbons, 'The Humanitarian Turn in Nuclear Disarmament and the Treaty on the Prohibition of Nuclear Weapons' (2018) 25(1–2) *Nonproliferation Review*, pp. 11–36.

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on the Non-Proliferation of Nuclear Weapons and the 2017 Treaty on the Prohibition of Nuclear Weapons,[28] are a case in point. The prohibition of nuclear weapons has been a reactive response to the detonation of two atomic bombs in the Second World War, but these treaties are also proactive because they aim to prevent such events from occurring in the future. Similarly, there is now a call by scientists and global civil society for the adoption of a Fossil Fuel Non-Proliferation Treaty in response to acknowledged past harm and to prevent future continued damage to climate systems from the use of fossil fuels.[29]

A common characteristic of prohibitory regimes is thus that they also contain measures *in anticipation* of potentially harmful consequences of certain activities, substances, or technologies. They are created within the realm of what has been called 'anticipatory governance', that is, decision-making in the present based on (imperfect) predictions of potential future harm or benefit. Anticipatory governance aims to prevent uncertain, not yet experienced, and often highly contested but potentially irreversible future harm, through taking preventive or precautionary measures in the present,[30] an increasingly important focus for law.[31]

An example of an anticipatory prohibition regime is the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention),[32] which contains a list of materials that must not be disposed of at sea. This Convention has evolved into the 1996 London Dumping Protocol's reverse list approach,[33] which lists those few substances that can still be disposed of at sea, while anything else is prohibited from being dumped, including substances the impact of which on the marine environment is as yet unknown.[34] The current and growing call for a moratorium on deep seabed mining led by some Pacific Island states and non-governmental organizations (NGOs) is another example.[35] Although the impacts of mining in general are well understood, little is known about deep sea ecosystems and the impact of deep seabed mining on marine biodiversity.[36]

[28] Treaty on the Non-Proliferation of Nuclear Weapons, Moscow (Russia), London (United Kingdom (UK)), Washington D.C., (US), 1 July 1968, in force 5 Mar. 1970, available at: https://treaties.unoda.org/t/npt; for the 2017 treaty see n. 24 above.

[29] See P. Newell, H. van Asselt & F. Daley, 'Building a Fossil Fuel Non-proliferation Treaty: Key Elements' (2022) 14 *Earth System Governance*, article 100159.

[30] A. Gupta, 'An Evolving Science-Society Contract in India: The Search for Legitimacy in Anticipatory Risk Governance' (2011) 36(6) *Food Policy*, pp. 736–41; J. Vervoort & A. Gupta, 'Anticipating Climate Futures in a 1.5°C Era: The Link between Foresight and Governance' (2018) 31 *Current Opinion in Environmental Sustainability*, pp. 104–11.

[31] E. Stokes, 'Beyond Evidence: Anticipatory Regimes in Law' (2021) 43(1) *Law & Policy*, pp. 73–91.

[32] London (UK), 13 Nov. 1972, in force 30 Aug. 1975, available at: https://www.imo.org/en/OurWork/Environment/Pages/London-Convention-Protocol.aspx (London Convention).

[33] London (UK), 7 Nov. 1996, in force 24 Mar. 2006, available at: https://www.imo.org/en/OurWork/Environment/Pages/London-Convention-Protocol.aspx (London Dumping Protocol).

[34] E.g., R. Coenen, 'Dumping of Wastes at Sea: Adoption of the 1996 Protocol to the London Convention 1972' (1997) 6(1) *Review of European Community & International Environmental Law*, pp. 54–61.

[35] See, e.g., Deepsea Conservation Coalition, 'Momentum for a Moratorium', available at: https://savethehighseas.org/moratorium_2022.

[36] E.g., K. Miller et al., 'Challenging the Need for Deep Seabed Mining from the Perspective of Metal Demand, Biodiversity, Ecosystems Services, and Benefit Sharing' (2021) 8 *Frontiers in Marine Science*, article 706161.

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The need for anticipatory governance in international law has gained renewed attention regarding so-called 'disruptive technologies', such as nanotechnology; biotechnology, genome editing and synthetic biology; artificial intelligence, neural nets and machine learning; sensors and the internet of things; as well as geoengineering.[37] These technologies carry a high degree of uncertainty and risk and any potential harm resulting from their deployment is considered to be so significant that states must approach them with caution: 'Their effects on natural environments and their processes are likely to be global, at best only partly predictable, and extend beyond their objective … [E]ven their predictable effects, including those of the objective itself, cannot be guaranteed to be benign'.[38] For these reasons, such disruptive technologies are sought to be approached with caution under the umbrella of anticipatory governance and the prohibitory provisions of international law.

Governments increasingly seem open to supporting the prohibition of certain harmful disruptive technologies. One example is the 2008 de facto moratorium on ocean fertilization; here the parties to the London Convention and London Dumping Protocol defined and prohibited ocean fertilization in a non-binding resolution adopted by consensus, with an exception for 'legitimate scientific research'.[39] A more permissive 2013 Resolution to amend the London Dumping Protocol will operationalize the 2008 Resolution and may result in different interpretations of it; this is not yet in force,[40] although six states have ratified the amendment[41] and some have transposed it into binding national law.[42]

2.4. Emergence and Evolution of Prohibitory Regimes

Generally, prohibitory or restrictive regimes evolve over lengthy periods of time. They sometimes begin as initiatives taken by a small group of countries or as voluntary guidelines developed by national and transnational organizations and civic movements, which subsequently become institutionalized as legally binding treaties.[43] For example, the negotiation of the Treaty on the Prohibition of Nuclear Weapons[44] was initiated in

[37] J. Thomas, 'An Overview of Emerging Disruptive Technologies and Key Issues' (2019) 62(1) *Development*, pp. 5–12; A. Gupta et al., 'Anticipatory Governance of Solar Geoengineering: Conflicting Visions of the Future and Their Links to Governance Proposals' (2020) 45 *Current Opinion in Environmental Sustainability*, pp. 10–9.

[38] P. Verlaan, 'Geo-engineering, The Law of the Sea and Climate Change' (2009) 3(4) *Carbon and Climate Law Review*, pp. 446–58, at 446.

[39] Resolution LC-LP.1, 'On the Regulation of Ocean Fertilization', 31 Oct. 2008, available at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/LCLPDocuments/LC-LP.1%20(2008).pdf; P. Verlaan, 'New Regulation of Marine Geo-engineering and Ocean Fertilization' (2013) 28 *The International Journal of Marine and Coastal Law*, pp. 729–36.

[40] 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', 18 Oct. 2013 available at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/LCLPDocuments/LP.4(8).pdf.

[41] M. Boettcher & R.E. Kim, 'Arguments and Architectures: Discursive and Institutional Structures Shaping Global Climate Engineering Governance' (2022) 128 *Environmental Science & Policy*, pp. 121–31.

[42] See Germany's *Hohe-See-Einbringungsgesetz*, available at: https://www.gesetze-im-internet.de/hohe-seeeinbrg/index.html.

[43] Nadelmann, n. 13 above, p. 480.

[44] N. 24 above.

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June 1998 by a small coalition of states consisting of Brazil, Egypt, Ireland, Mexico, New Zealand, and South Africa, and it was only in July 2017 that 122 states voted in favour of adopting the treaty.[45]

A distinct approach, but one that might be suitable for the manner in which a non-use agreement on solar geoengineering might evolve, is the 1997 Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction (Landmines Ban Convention).[46] This treaty developed from a global non-use movement involving transnational and domestic NGOs, UN personnel and agencies, influential human rights and development organizations, and a small set of supportive and sponsoring countries.[47] The Landmines Ban Convention illustrates that restrictive global regimes can be successfully constructed despite opposition from powerful countries, such as the US. It also demonstrates that such regimes can then shape US policy and behaviour abroad, even if the country opts to remain outside the prohibitory regime.

3. Key Elements of a Solar Geoengineering Non-Use Regime: Lessons from International Law

Having sketched the context, broader objectives, and some key principles and motivations underpinning international prohibitory regimes, we now examine specific design elements in such regimes to draw lessons for a potential future non-use agreement on solar geoengineering. We focus on the object of prohibitions and restrictions (i.e., *what* is to be prohibited or restricted) in Section 3.1; the mechanisms by which to seek prohibitions and restrictions (i.e., *how* prohibitions or restrictions are organized) in Section 3.2; decision-making procedures and voting rules (Section 3.3); systems of compliance control and monitoring (Section 3.4); the legal consequences of non-compliance (Section 3.5); and the regulation of activities by private actors (Section 3.6).

3.1. The Object of Prohibitions and Restrictions (the 'What')

What exactly should be prohibited or restricted? Drawing on existing examples in international law, we outline here a variety of objects of prohibition and restriction, in terms of activities, substances, or purpose. Such prohibitions or restrictions cover a spectrum from research, (field) experimentation and technology development, to deployment and use.

[45] J. Borrie et al., 'A Prohibition on Nuclear Weapons: A Guide to the Issues', United Nations Institute for Disarmament Research & International Law and Policy Institute, Feb. 2016, p. 20, available at: https://unidir.org/files/publication/pdfs/a-prohibition-on-nuclear-weapons-a-guide-to-the-issues-en-647.pdf.

[46] Oslo (Norway), 18 Sept. 1997, in force 1 Mar. 1999, available at: https://www.apminebanconvention.org.

[47] K. Brinkert, 'The Convention Banning Anti-Personnel Mines: Applying the Lessons of Ottawa's Past in Order to Meet the Challenges of Ottawa's Future' (2003) 24(5) *Third World Quarterly*, pp. 781–93; P. Herby & E. La Haye, 'How Does It Stack Up? The Anti-Personnel Mine Ban Convention at 10', *Arms Control Today*, 2007, available at: https://www.armscontrol.org/act/2007-12/features/does-stack-up-anti-personnel-mine-ban-convention-10; R. Goldblat, 'Anti-Personnel Mines: From Mere Restrictions to a Total Ban' (1999) 30(1) *Security Dialogue*, pp. 9–23.

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Prohibiting illegitimate research

The first object of potential prohibitions and restrictions relates to scientific research, including field experimentation, especially where this is linked to technology development. In many international regimes dealing with prohibited technologies or activities, 'legitimate' scientific research is generally permitted and is hence exempted from a regime's general prohibition. However, this is not so in all cases. There are precedents for outright prohibitions on certain types of scientific research in international regimes, if such research violates key principles of international law, such as the no-harm or the precautionary principle. This includes field research and experimentation that either itself leads to harmful consequences or is intended to feed directly into the development of certain prohibited activities or technologies. An example is the regime that prohibits research aimed at the development and production of chemical weapons.[48] This can provide a model for a similar approach to be adopted for a solar geoengineering non-use agreement. Another example is the Comprehensive Nuclear-Test-Ban Treaty,[49] which bans all forms of nuclear testing, whether for military or peaceful purposes.

Restricting or exercising oversight over legitimate research

Where not prohibited outright, many international regimes nonetheless restrict or exercise oversight over (certain types of) scientific research and experimentation. For example, under the International Convention for the Regulation of Whaling,[50] a special permit must be obtained for scientific research and all such permits must be reported to the International Whaling Commission.[51] The Protocol on Environmental Protection to the Antarctic Treaty lists various criteria to be considered when authorizing scientific research, including the scale of the activity and its impact.[52] In both cases, full disclosure of scientific results is required and research should not be used for commercial purposes.[53] This latter consideration also highlights the focus on regulating intent or purpose of the scientific research in question as an object of prohibition.

Even for permitted scientific research, therefore, some form of oversight may be required, also to ensure that research results are not misused to engage in the restricted or prohibited activity. This oversight can take the form of a set of criteria against which research proposals are assessed on a case-by-case basis (as in the Antarctic Protocol).[54] As another prominent example, under the London Dumping Protocol[55] an assessment

[48] Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (Chemical Weapons Convention), Paris (France), 13 Jan 1993, in force 29 Apr. 1997, available at: https://www.opcw.org/chemical-weapons-convention. See J.P. Robinson, *Chemical Warfare Arms Control: A Framework for Considering Policy Alternatives* (Routledge, 2021).

[49] New York, NY (US), 10 Sept. 1996, not in force, available at: https://www.ctbto.org/our-mission/the-treaty.

[50] Washington, DC (US), 2 Dec. 1946, in force 10 Dec. 1948, available at: https://iwc.int/convention.

[51] Available at: https://iwc.int.

[52] N. 18 above, Art. 3.2(c).

[53] E. Molenaar & A. Elferink, 'The Law of the Sea and the Polar Regions', in R. Lefeber (ed.), *Marine Scientific Research in the Antarctic Treaty System* (Brill, 2013), pp 323–34.

[54] N. 18 above.

[55] N. 33 above.

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framework has been developed to determine whether specific proposals for ocean fertilization constitute legitimate scientific research, including criteria such as exposure, effects, risks, and uncertainties.[56]

Similarly, a far-reaching decision specific to geoengineering under the Convention on Biological Diversity (CBD)[57] provides that geoengineering must not take place until specific conditions are fulfilled; notably, that there must be an adequate scientific basis on which to justify such activities, and risks to the environment and biodiversity and associated social, cultural, and economic impacts have been appropriately considered.[58] Exempt from this provision, however, are:

> small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the [CBD], and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.[59]

Finally, information clearing houses set up under the Cartagena Protocol on Biosafety governing the safe transboundary transfers of living modified organisms,[60] and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization,[61] both adopted under the CBD, seek to improve the clarity and transparency of permitted scientific research and/or risk assessments. For solar geoengineering-related research, including that being funded by philanthropic and private organizations,[62] governments could develop regulations to ensure that information on such research is required to be reported and shared through such an intergovernmental clearing house.

Prohibitions on public funding

As another innovative regime design element, restrictions or prohibitions can be placed on public funding for research and experimentation that is linked directly to technology development, or for technology development itself. Such restrictions or prohibitions on

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[56] See International Maritime Organization, Resolution LC-LP.2(2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization, adopted 14 Oct 2010, available at: https://www.imo.org/en/OurWork/Environment/Pages/AssessmentFramework-default.aspx.

[57] Rio de Janeiro (Brazil), 5 June 1992, in force 29 Dec. 1993, available at: http://www.cbd.int/convention.

[58] CBD, 10th Conference of the Parties (COP-10), Decision X/33, 'Biodiversity and Climate Change', 29 Oct. 2010, UN Doc. UNEP/CBD/COP/DEC/X/33, para. 8(w), available at: https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-33-en.pdf.

[59] Ibid.

[60] Montreal (Canada), 29 Jan. 2000, in force 11 Sept. 2003, available at: http://bch.cbd.int/protocol. See also A. Gupta, 'Transparency to What End? Governing by Disclosure through the Biosafety Clearing House' (2010) 28(1) *Environment and Planning C: Government and Policy*, pp. 128–44.

[61] Nagoya (Japan), 29 Oct. 2010, in force 12 Oct. 2014, available at: https://www.cbd.int/abs/doc/protocol/nagoya-protocol-en.pdf.

[62] E. Necheles et al., 'Funding for Solar Geoengineering from 2008 to 2018', *Harvard's Solar Geoengineering Research Program Blog*, 13 Nov. 2018, available at: https://geoengineering.environment.harvard.edu/blog/funding-solar-geoengineering; see also K. Surprise & J.P. Sapinski, 'Whose Climate Intervention? Solar Geoengineering, Fractions of Capital, and Hegemonic Strategy' (2022) 47(4) *Capital & Class*, pp. 539–64; and Stephens et al., n. 7 above.

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public funding are implicit in international regimes that prohibit the research, development, production, and use of chemical[63] and biological weapons.[64]

There are also precedents for this in the domestic laws of some countries, particularly in relation to human cloning. For example, since the 1990s, successive US governments have banned federal funding for human cloning research, including research using stem cells derived from human cloning.[65] Voluntary announcements by some governments that they will no longer provide public funding for fossil fuel projects overseas[66] is another example of how countries can divert public investment away from undesirable technological development. Such domestic precedents for withdrawing public funding could also be useful elements in designing a non-use regime to inhibit future development of solar geoengineering technologies.

Prohibitions on technology development

Experimentation into and development of specific techniques and intervention methods for deployment could also be restricted or prohibited, such as balloons or specialized aircraft in the case of solar geoengineering.

Stratospheric injection of aerosols for solar geoengineering would require, for example, specialized high-altitude aircraft to inject reflective particles into the stratosphere. Irrespective of whether existing aircraft could be used[67] or whether new aircraft are needed,[68] such dedicated aircraft could be identified and distinguished from others, and their development and deployment could be restricted. This could be the case also for related technologies, such as balloons for the spraying of particles into the stratosphere.

Prohibitions on deployment and use, including injection of substances

There are many examples where the actual deployment and use of specific risky or dangerous technologies or activities is prohibited or regulated under international law.

The treaties on chemical and biological weapons discussed above have the most far-reaching comprehensive prohibitions covering deployment and use, with the biological weapons regime prohibiting, for example, the development, production, acquisition,

[63] Chemical Weapons Convention, n. 48 above.

[64] Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction (Biological Weapons Convention), Geneva (Switzerland), 10 Apr. 1972, in force 26 Mar. 1975, available at: https://disarmament.unoda.org/biological-weapons.

[65] The Witherspoon Council on Ethics and the Integrity of Science, 'The Threat of Human Cloning' (2015) 46 *The New Atlantis*, pp. 5–6, available at: https://www.thenewatlantis.com/publications/the-threat-of-human-cloning.

[66] K. Abnett & S. Jessop, 'US, Canada among 20 Countries to Commit to Stop Financing Fossil Fuels Abroad', *Reuters*, 4 Nov. 2021, available at: https://www.reuters.com/business/cop/19-countries-plan-cop26-deal-end-financing-fossil-fuels-abroad-sources-2021-11-03.

[67] W. Smith & G. Wagner, 'Stratospheric Aerosol Injection Tactics and Costs in the First 15 Years of Deployment' (2018) 13(12) *Environmental Research Letters*, article 124001.

[68] D. Bingaman et al., 'A Stratospheric Aerosol Injection Lofter Aircraft Concept: Brimstone Angel', presentation at the American Institute of Aeronautics and Astronautics Scitech 2020 Forum, Orlando, FL (US), 6–10 Jan. 2020, available at: https://arc.aiaa.org/doi/10.2514/6.2020-0618.

transfer, stockpiling, and use of biological weapons.[69] This is a broad prohibition intended to prevent unilateral deployment and proliferation of such weapons.

Another relevant way to prevent deployment and use of risky interventions is to prohibit the act of injecting a substance into a medium. For example, ocean fertilization by dumping iron powder at sea is regulated and still largely prohibited under the London Dumping Protocol[70] and the CBD (except, as noted above, for purposes of legitimate scientific research).[71] Other legal frameworks, such as the 1979 Convention on Long-Range Transboundary Air Pollution,[72] limit the release of substances such as sulphate aerosols if they are linked to acid rain,[73] and its 1998 Aarhus Protocol prohibits emissions of heavy metals.[74]

Prohibitions on military use

The final important precedent from existing regimes relates to strong prohibitions on military use of certain prohibited or restricted activities and technologies. For example, the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD)[75] prohibits hostile environmental modification, permitting such modifications only for peaceful purposes. In the case of solar geoengineering, peaceful intent can be questioned or be hard to establish *ex ante*, as has been the case with many environmental modification interventions.[76] As such, a role for the military in any future deployment of solar geoengineering, as well as in real or suspected attempts at its weaponization, would need to be a core focus of prohibitions.[77] Prohibiting the retrofitting of military fighter aircraft to inject aerosols into the stratosphere has already been discussed above.[78] Prohibiting the use of military personnel or equipment for solar geoengineering would be critical both for transparency and accountability, and in order to prevent a key avenue for future development and deployment of these technologies.

[69] Biological Weapons Convention, n. 64 above.

[70] See nn. 33 and 39 above. The London Dumping Protocol itself prohibits dumping at sea, except for permitted items. Iron powder is now permitted for small-scale ocean iron fertilization experimentation under the resolution, but this has not yet entered into force. See also n. 40 above and associated text.

[71] N. 57 above.

[72] Geneva (Switzerland), 13 Nov. 1979, in force 16 Mar. 1983, available at: https://unece.org/sites/default/files/2021-05/1979%20CLRTAP.e.pdf.

[73] D. Visioni, E. Slessarev & L. Xia, 'What Goes Up Must Come Down: Impacts of Deposition in a Sulfate Geoengineering Scenario' (2020) 15(9) *Environmental Research Letters*, article 094063.

[74] Aarhus Protocol on Heavy Metals to the 1979 Convention on Long-Range Transboundary Air Pollution, Aarhus (Denmark), 24 June 1998, in force 29 Dec. 2003, as amended on 13 Dec. 2012, in force 8 Feb. 2022, both available at: https://unece.org/environment-policy/air/protocol-heavy-metals.

[75] Geneva (Switzerland), 18 May 1977, in force 5 Oct. 1978, available at: https://disarmament.unoda.org/enmod.

[76] R. Pincus, '"To Prostitute the Elements": Weather Control and Weaponization by US Department of Defense' (2017) 36(1) *War & Society*, pp. 64–80.

[77] D. Jayaram & M.C. Brisbois, 'Aiding or Undermining? The Military as an Emergent Actor in Global Climate Governance' (2017) 9 *Earth System Governance*, article 100107.

[78] A. Robock et al., 'Benefits, Risks, and Costs of Stratospheric Geoengineering' (2009) 36(19) *Geophysical Research Letters*, article L19703.

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3.2. Prohibitory and Restrictive Governance Mechanisms (the 'How')

There are many ways in which international regimes restrict or prohibit specific actions to minimize or rule out adverse impacts. The strongest form of prohibition is an outright ban without any exceptions. For example, Protocol I on Non-detectable Fragments to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons which may be Deemed to be Excessively Injurious or to Have Indiscriminate Effects[79] strictly prohibits the 'use [of] any weapon the primary effect of which is to injure by fragments which in the human body escape detection by X-rays'.[80] The focus of this provision is aimed squarely at unconditionally prohibiting the use of any weapon with the stated effects.

However, there are various ways, beyond an outright ban, through which restrictive and prohibitive norms are designed and legal techniques chosen to facilitate the prohibition or restriction. We identify and outline below five key such techniques, including their advantages and disadvantages, that are used in existing legal regimes, with lessons for prohibiting or restricting potential future use of solar geoengineering.

Interpreting prohibitions

Firstly, prohibitions can be purposefully framed in general terms, which leaves room for flexibility in subsequent interpretation in state practice. One example is the ENMOD, which states in its Article 1 that '[e]ach State Party … undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party'.[81] The Convention does not use unequivocal terminology such as 'prohibition' but relies on a 'softer' mutual agreement, with the exact scope of prohibition depending upon the interpretation of words such as 'environmental modification',[82] 'severe effects',[83] and 'peaceful purposes'. These qualifiers require further precision to define the (broad or narrow) scope of prohibition in specific cases. This implies, as well, that in the implementation of the agreement there is considerable room for politically contested interpretative decisions. Such interpretative decisions by, for example, conferences of the parties (COPs) or international courts, are not limited to resolving conflicts in an individual case but can also influence future cases, with implications for delimiting or expanding a broad and general scope. While hard to prevent in practice, it should be noted that relying on a broad scope prohibition and interpretative flexibility may not be an ideal technique for a highly contested issue such as solar geoengineering.

[79] Both adopted at Geneva (Switzerland), 10 Apr. 1980, into force 2 Dec. 1983, both available at: https://disarmament.unoda.org/the-convention-on-certain-conventional-weapons.

[80] Ibid., Protocol 1.

[81] ENMOD, n. 75 above, Art. 1.

[82] Ibid., Art. 1 ('deliberate manipulation of natural processes—the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space').

[83] Report of the Conference of the Committee on Disarmament, Vol. I, *UN General Assembly Official Records: 31st Session – 1976*, Supplement No. 27 (A/31/27), pp. 91–2, available at: https://digitallibrary.un.org/record/697097?ln=en.

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Modifying prohibitions

Secondly, in addition to clearly worded bans or qualified prohibitions, governments can include prohibitions that can be modified over time through annexes to treaties. One example of adopting the annex technique is the Montreal Protocol on Substances that Deplete the Ozone Layer,[84] which facilitates a stepwise phase-out of the consumption and production of ozone depleting substances by adding annexes. The Protocol also includes flexible 'adjustments', which enable parties to respond to new scientific information and agree to accelerate the reduction schedules for chemicals already covered in the annexes to the Protocol.

The 'annex approach' thus offers considerable agility to add prohibitions in annexes without reopening a whole treaty for time-consuming interstate negotiations. Regarding the prohibition of solar geoengineering, the annex technique could be used for amending and increasing the scope of a regime (and its general prohibition) over time, although this would need to be aligned with existing international law pertinent to solar geoengineering.[85] Using an annex approach, governments could add more specific obligations or respond to new developments in science, while maintaining an overall general prohibition. In the case of solar geoengineering, the annex technique would come close to interpretative clarifications on prohibitions, but with more flexibility and more multilaterally negotiated outcomes than ad hoc and context-specific interpretations.

Specifying prohibitions

Thirdly, a general prohibition could be further elaborated by adding specific prohibitions in the treaty text itself. Examples are the Chemical Weapons[86] and the Biological Weapons Conventions.[87] While Article I of the Chemical Weapons Convention has a general prohibition on the possession, development, production, and use of chemical weapons, Articles IV and V set out specific restrictions on states that possess chemical weapons, and on related production facilities. The Biological Weapons Convention has similar specific prohibitions in addition to the general prohibition of biological weapons.[88] Neither of the treaty texts, however, indicates the exact relationship between the general prohibition and specific provisions. These additional specific prohibitions could be regarded as superfluous in that they overlap with

[84] Montreal (Canada), 16 Sept. 1987, in force 1 Jan. 1989, available at: https://ozone.unep.org/treaties/montreal-protocol.

[85] This includes, e.g., a 'de facto moratorium' under CBD Decision X/33, n. 58 above. Although non-binding, this Decision could be read as calling for a general prohibition on all solar geoengineering that may affect biodiversity, with some exceptions for small-scale scientific studies. The Decision stipulates that geoengineering must not take place until specific conditions are fulfilled: ibid., para 8(w); see further Section 3.1, and related references.

[86] N. 48 above.

[87] N. 64 above.

[88] Art. I of the Biological Weapons Convention (ibid.) contains the general prohibition to 'develop, produce, stockpile or otherwise acquire or retain' the covered items. Art. II adds to this and sets out what states actively shall do 'to destroy, or to divert to peaceful use', and adds to what objects are attributed to a state ('in its possession or under its jurisdiction or control').

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each other or are even fully contained in the overarching prohibition;[89] to some extent they are even contradictory.[90] However, they do have the function of operationalizing the general prohibition. In a sense, the more specific prohibitions echo the general prohibition and address it in subparts. However, the general prohibition is nonetheless broader than simply the sum of the specific prohibitions. With regard to solar geoengineering, a general prohibition on the development and use of such technologies could, for example, be accompanied by more specific and concrete prohibitions on production facilities, or aviation technologies or centres.

Prohibition through restriction

Fourthly, international treaties not only prohibit illegal activities; they often also restrict legal activities. In the latter case, an activity is not prohibited as such but falls under specific modalities or limitations. Typically, treaties clearly indicate whether an activity as such is legal or illegal. The monitoring of legal activities has a precautionary function in respect of the general prohibition of a treaty. Monitoring prevents, under the disguise of a legal activity, illegal activities from taking place or being prepared. In a sense, the restrictions are the outer protective layer of the core prohibition. The Treaty on the Non-Proliferation of Nuclear Weapons[91] and the Chemical Weapons Convention are typical examples. While the first pillar of the non-proliferation treaty is the prohibition of the development of nuclear weapons by so-called non-nuclear states, the second pillar relates to safeguards and monitoring of the peaceful use of nuclear technologies in a way that does not allow for the development of weapons technologies.

Regarding solar geoengineering, a general prohibition could be accompanied by restrictions and procedural requirements on legal activities, while ensuring transparency and compliance with the general prohibition. The agreement could, for example, leave policy space for governments to provide for safeguards for local (rather than global) applications, as some Australian experts have proposed in order to protect the Great Barrier Reef.[92] Such potentially 'local' applications of solar radiation modification could then be specifically exempt from a general global prohibition of solar geoengineering, but would still be subject to global restrictions, such as procedural provisions enhancing transparency.

Conditional prohibition

Fifthly, some existing legal regimes combine a prohibition with the possibility of lifting or modifying this prohibition under specified conditions over time. This also offers the possibility to grant exemptions if the overall situation changes, or in case of new developments. One example is the prohibition of mining in Antarctica. The Protocol on

[89] E.g., the prohibition of chemical weapons already implies not to have production facilities for chemical weapons.

[90] E.g., in the Chemical Weapons Convention (n. 48 above) the obligations to destroy a prohibited object (Art. IV) or to make declarations on prohibited items (Art. III.1) seem to assume that Art. I is violated.

[91] N. 28 above.

[92] J. McDonald et al., 'Governing Geoengineering Research for the Great Barrier Reef' (2019) 19(7) *Climate Policy*, pp. 801–11.

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Environmental Protection to the Antarctic Treaty[93] imposes a general prohibition on mining activities on that continent, but also provides that after 50 years and under specific qualified procedures, this ban can be modified by a future legally binding agreement that contains substantive safeguards.[94]

Another example is the emerging deep seabed mining regime, where a prohibition is stipulated, while allowing exemptions to be granted in the future under certain conditions. However, mining outside the control of the International Seabed Authority (ISA) and without its authorization remains prohibited.[95] Under a prohibitory regime on solar geoengineering, a treaty body could decide, for instance, to authorize some research activities that a large majority of governments see as less problematic or even desirable, comparable with CBD COP Decision X/33, which permits exemptions for some types of research activity under restrictive conditions.[96]

In sum, numerous legal techniques exist that could give shape to a general prohibition on solar geoengineering in a future international regime. Such a general prohibition could be qualified in various ways, depending on the political compromises needed. A general prohibition on the development and deployment of solar geoengineering could provide for restrictive permissions for local (and locally confined) deployment. It might also establish a framework for future revisions under specific conditions, and it could include annexes that differentiate between legitimate research and the prohibited development of solar geoengineering technologies.

3.3. Decision-Making Procedures

Any international regime that seeks to prohibit or regulate the development and use of risky technologies at the planetary level requires effective decision-making procedures that are seen as fair and legitimate by all actors affected by such decisions. What lessons can be drawn from existing regimes on such essential principles, and the decision-making procedures that might embody them?

Sovereign equality: 'One country, one vote'

The most common approach in international regimes and organizations derives from the principle of sovereign equality, which grants each country an equal vote. This principle is enshrined in Article 18 of the Charter of the United Nations[97] and guides most

[93] N. 18 above, Art. 3.

[94] Ibid., Art. 25(V)(a) ('… binding legal regime on Antarctic mineral resource activities that includes an agreed means for determining whether, and, if so, under which conditions, any such activities would be acceptable. This regime shall fully safeguard the interests of all States referred to in Article IV of the Antarctic Treaty and apply the principles thereof').

[95] UNCLOS, n. 20 above, Part XI. See also C. Blanchard et al., 'The Current Status of Deep-Sea Mining Governance at the International Seabed Authority' (2023) 147 *Marine Policy*, article 105396. For the ISA, see https://www.isa.org.jm.

[96] N. 58 above. See also CBD Secretariat, 'Climate-related Geoengineering and Biodiversity: Technical and Regulatory Matters on Geoengineering in relation to the CBD', available at: https://www.cbd.int/climate/geoengineering.

[97] San Francisco, CA (US), 26 June 1945, in force 24 Oct. 1945, available at: https://www.un.org/en/about-us/un-charter.

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other international organizations and treaty regimes. The quorum for eventual decisions varies, from the requirement of consensus (as in the United Nations Framework Convention on Climate Change (UNFCCC)[98]) to various forms of qualified or simple majority voting.[99] If applied to the hypothetical governance of solar geoengineering, the principle of sovereign equality would imply – assuming quasi-universality – a dominant influence of developing countries, which would account for about 130 of approximately 190 votes. This influence would be roughly in line with the distribution of the global population. The UNFCCC COP in Sharm-el-Sheikh (Egypt) in 2022 demonstrated, for example, that the global south can, on matters of perceived joint interest, still act as a united voting bloc, despite internal differences.[100] Even though their interests and perspectives may vary, should the negotiating group of developing countries decide to take a joint stance when it comes to planetary-scale solar geoengineering, this would constitute a majority position under most UN decision-making procedures.

Weighted voting to advantage 'major powers'

Some advocates of solar geoengineering research argue that the principle of 'one country one vote' may be unrealistic, because 'major powers' (often a veiled reference to the US) may not accept majority decisions by developing countries when it comes to planetary-scale solar geoengineering.[101] Some of these advocates of solar geoengineering research therefore suggest the explicit placing of binding decisions on deployment in the hands of only a small group of powerful countries ('target states').[102]

[98] New York, NY (US), 9 May 1992, in force 21 Mar. 1994, available at: https://unfccc.int. See also A. Vihma, 'Climate of Consensus: Managing Decision Making in the UN Climate Change Negotiations' (2015) 24(1) *Review of European, Comparative & International Environmental Law*, pp. 58–68.

[99] E.A. Posner & A.O. Sykes, 'Voting Rules in International Organisations' (2013) 15(1) *Chicago Journal of International Law*, pp. 195–228.

[100] The global south spoke with a united voice calling for a loss and damage facility to be established at UNFCCC COP27 in Egypt, even though the group consists of very diverse large and small economies (i.e., emerging economies and small island developing states), with different perspectives and concerns on the topic; see T. Singh, 'As COP27 Proceeds, Global South Calls on North To Get Serious About Climate Funding', *Peoples Dispatch*, 11 Nov. 2022, available at: https://peoplesdispatch.org/2022/11/11/as-cop27-proceeds-global-south-calls-on-north-to-get-serious-about-climate-funding.

[101] J.L. Reynolds, *The Governance of Solar Geoengineering: Managing Climate Change in the Anthropocene* (Cambridge University Press, 2019); Z. Dove, J. Horton & K. Ricke, 'The Middle Powers Roar: Exploring a Minilateral Solar Geoengineering Deployment Scenario' (2021) 132 *Futures*, article 102816; E.A. Parson & J.L. Reynolds, 'Solar Geoengineering Governance: Insights from a Scenario Exercise' (2021) 132 *Futures*, article 102805; for a critique of non-inclusive governance approaches recommended by advocates of solar geoengineering research see also D. Humphreys, 'Smoke and Mirrors: Some Reflections on the Science and Politics of Geoengineering' (2011) 20(2) *The Journal of Environment & Development*, pp. 99–120.

[102] See Reynolds, ibid., pp. 215–6, for the argument that participation of 'target states' should be privileged in global decision-making on solar geoengineering deployment. As he puts it, these 'target states' include 'states with the capacity, international political clout and willingness to implement solar geoengineering (or counter-solar geoengineering) in a sustained manner … . These presently number perhaps one or two dozen' … [as well as] 'other states with the relative power and willingness to retaliate in other issue-areas in response to solar geoengineering activities with which they disagree. This would be a handful of great powers … . I collectively call these two groups the "target states"': ibid., p. 215. Reynolds goes on to

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There are indeed precedents in international law for decision-making systems that privilege the special interests of 'major powers'.[103] One example is the UN Security Council, which grants permanent membership and a veto right to five countries that were perceived as particularly powerful in 1945 – namely, China, France, Russia, the United Kingdom (UK), and the US.[104] In the World Bank and the International Monetary Fund decision-making procedures, votes are weighted according to the funds that (donor) countries invest, again granting disproportionate power to larger industrialized countries, notably the US.[105] The Antarctic Treaty[106] requires voting members to conduct 'substantial scientific research' in Antarctica, which again effectively excludes smaller and poorer developing countries.[107] The Council of the International Maritime Organization prioritizes seats according to a country's economic interest in shipping, granting special seats to major shipping nations and sea-trading nations.[108] As a final example, in the ISA, which governs deep seabed mining, half of the seats in its 36-member Council are reserved for countries with especially high consumption levels of such minerals; countries with the largest investments in such activities or the main exporters of such minerals, as well as six developing countries with 'special interests'. The remainder of the seats are allocated to ensure geographical representation based on UN classifications.[109]

Most of these instances of weighted voting privilege the interests of the so-called 'global north' or industrialized countries, and reflect, and perpetuate, the colonial structures of 1945 when most of the world was occupied or controlled by European countries and the US. When it comes to solar geoengineering at the planetary scale, however, such a system of weighted voting to protect interests of 'major powers' could be perceived as grossly unfair and would be unlikely to be acceptable to most developing countries. One can assume that these countries instead would support a

discuss a two-tier global decision-making system to govern deployment of solar geoengineering, whereby the few 'target states' would have decisive political control in an 'executive committee', while other states would have a voice only in a second-tier 'general assembly' with non-binding authority: ibid., p. 216.

[103] E. McIntyre, 'Weighted Voting in International Organizations' (2009) 8(4) *International Organization*, pp. 484–97.

[104] O.G. Afoaku & O. Ukaga, 'United Nations Security Council Reform: A Critical Analysis of Enlargement Options' (2001) 18(2) *Journal of Third World Studies*, pp. 149–69.

[105] W.N. Gianaris, 'Weighted Voting in the International Monetary Fund and the World Bank' (1990) 14(3) *Fordham International Law Journal*, pp. 910–45.

[106] Washington, DC (US), 1 Dec. 1959, in force 23 June 1961, available at: https://www.ats.aq/e/key-documents.html. Art. IX(2) states: 'Each Contracting Party which has become a party to the present Treaty … shall be entitled to appoint representatives to participate in the meetings referred to in paragraph 1 of the present article, during such time as that Contracting Party demonstrates its interest in Antarctica by conducting substantial scientific research activity there, such as the establishment of a scientific station or the despatch of a scientific expedition'.

[107] Y. Yermakova, 'Legitimacy of the Antarctic Treaty System: Is It Time for a Reform?' (2021) 11(2) *Polar Regions and Multi-Level Governance*, pp. 342–59.

[108] Convention on the International Maritime Organization, Geneva (Switzerland) 6 Mar. 1948, in force 17 Mar. 1958, Part VI, Art. 17 (The Council), available at: https://treaties.un.org/doc/Treaties/1958/03/19580317%2005-05%20PM/Ch_XII_1p.pdf; see also H. Canton, 'International Maritime Organization: IMO', in Europa Publications (ed.), *The Europa Directory of International Organizations 2021* (Routledge, 2021), pp. 338–42.

[109] ISA, 'Composition of the Council', available at: https://www.isa.org.jm/organs/the-council.

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system that ensures sovereign equality of all countries rather than privileging those with greater access to or possession of solar geoengineering-related research and technology.

Weighted voting to advantage vulnerable countries

Some advocates of solar geoengineering research argue that their efforts would eventually benefit vulnerable countries in the global south and that it is, therefore, a moral obligation for research institutions in the global north to explore and develop planetary-level technologies for solar geoengineering.[110] Taking this logic to its final consequence, one could argue that these vulnerable countries should have the final say in decisions on solar geoengineering, and that technologies for solar geoengineering should be placed under the control of an executive committee made up of representatives of the African Union, the Climate Vulnerable Forum, the Alliance of Small Island States, and similar. Alternatively, international decisions on solar geoengineering could be weighted in favour of the least developed and vulnerable countries or grant a veto right to these countries.[111]

To date, however, there is no example of an international voting system that weighs votes in line with the vulnerability of countries. Instead, in some areas of global governance, such as on the use of armed force, the precedent is rather for mere consultation with developing countries.[112] In the case of solar geoengineering as well, advocates of more research into these technologies suggest a 'two-tier' global governance system for deployment decisions that would bestow binding decision-making authority on an 'executive committee' of only a small group of powerful countries ('target states') while granting other countries a voice only in a general assembly with non-binding authority.[113]

Weighted voting linked to emissions reductions

An alternative decision-making system could be to link voting rights to past emissions reduction; that is, to exclude those countries from decisions on solar geoengineering that have not contributed sufficiently to global mitigation goals or have very high levels of greenhouse gas emissions.[114] The application of such a system would require agreement on benchmarks by which voting rights would be reduced or repealed, a highly politically contentious question. The 2015 Paris Agreement,[115] under the UNFCCC,

[110] J. Horton & D. Keith, 'Solar Geoengineering and Obligations to the Global Poor', in C.J. Preston (ed.), *Climate Justice and Geoengineering: Ethics and Policy in the Atmospheric Anthropocene* (Rowman & Littlefield, 2016), pp. 79–92.

[111] A. Atiq Rahman et al., 'Developing Countries Must Lead on Solar Geoengineering Research' (2018) 556(7699) *Nature*, pp. 22–24.

[112] J. Westra, *International Law and the Use of Armed Force: The UN Charter and the Major Powers* (Routledge, 2007).

[113] Reynolds, nn. 101 and 102 above.

[114] For idealized discussions, the political legitimacy and feasibility of which would need to be considered, see E.A. Parson, 'Climate Engineering in Global Climate Governance: Implications for Participation and Linkage' (2014) 3(1) *Transnational Environmental Law*, pp. 89–110; J.L. Reynolds, 'Linking Solar Geoengineering and Emissions Reductions: Strategically Resolving an International Climate Change Policy Dilemma' (2022) 22(3) *Climate Policy*, pp. 285–300.

[115] Paris (France), 12 Dec. 2015, in force 4 Nov. 2016, available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

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does not offer such a benchmark, as countries are allowed to set their own national targets without a global allocation system.[116] The pre-condition for voting rights linked to (minimum) success in emissions reduction would thus be equivalent to the 1997 Kyoto Protocol to the UNFCCC,[117] with its legally binding quantified emissions reduction targets for each industrialized country.[118] The reinstatement of such an approach is unlikely at present.[119]

Alternatively, if the fairness principle of equal per-capita emissions allocation were to be agreed in such a new regime, it would inevitably exclude many high-emitting industrialized countries from voting on solar geoengineering decisions, with political implications akin to majority voting in the United Nations General Assembly (UNGA). In other words, the dominant weight in decisions, in this scenario, would lie with low-emitting developing countries, which is likely to be unacceptable to major powers such as the US.

Double weighted majority voting

One final example is the double-weighted majority voting adopted in 1990 for certain decisions under the 1987 Montreal Ozone Protocol.[120] Here, decisions require a simple majority of developing countries and a simple majority of industrialized countries at the same time.[121] In the current context, however, the question arises whether developed and developing country lists dating from the 1980s and 1990s would fit a future political context after 2040, when solar geoengineering, as its proponents argue, might need to be deployed. Yet, new country lists would be cumbersome and complicated to agree.

Decision making in a non-use regime

In short, an international decision-making system for potential planetary-level, multigenerational deployment of solar geoengineering that would be acceptable to the US, the EU, *and* to most countries in the global south is implausible, and there is no precedent for such a system. At present, decision making in international institutions follows

[116] S.K. Rose et al., 'The Paris Agreement and Next Steps in Limiting Global Warming' (2017) 142(1) *Climate Change*, pp. 255–70.

[117] Kyoto (Japan), 11 Dec. 1997, in force 16 Feb. 2005, available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf.

[118] M. Grubb, C. Vrolijk & D. Brack, *Kyoto Protocol: A Guide and Assessment* (Routledge, 2017).

[119] S. Jolly & A. Trivedi, 'Principle of CBDR-RC: Its Interpretation and Implementation through NDCS in the Context of Sustainable Development' (2021) 11(3) *Journal of Environmental Law and Policy*, pp. 309–22; S. Klinsky & A. Gupta, 'Taming Equity in Multilateral Climate Politics: A Shift from Responsibilities to Capacities', in J. Meadowcroft et al. (eds), *What Next for Sustainable Development: Our Common Future at Thirty* (Edward Elgar, 2019), pp. 159–79.

[120] N. 84 above, as amended by the London Amendment, COP-2 Dec. II/2, London (UK), 29 June 1990, in force 10 Aug. 1992, Art. 1(h) and (t), available at: https://treaties.un.org/doc/Treaties/1992/08/19920810%2003-51%20AM/Ch_XXVII_02_bp.pdf.

[121] E.g., Art. 2(9)(c) of the Montreal Protocol as amended ('If all efforts at consensus have been exhausted, and no agreement reached, such decisions shall, as a last resort, be adopted by a two-thirds majority vote of the Parties present and voting representing a majority of the Parties operating under Paragraph 1 of Article 5 present and voting and a majority of the Parties not so operating present and voting'). See F. Biermann, 'Financing Environmental Policies in the South: Experiences from the Multilateral Ozone Fund' (1997) 9(3) *International Environmental Affairs*, pp. 179–218.

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the 'One country one vote' system which grants overwhelming majorities for the global south, or it follows outdated weighted voting systems that draw on colonial considerations of the 1940s or highly unequal bargaining processes in the decades since.

However, for a possible non-use agreement on solar geoengineering that would simply seek to prohibit the development and deployment of solar geoengineering technologies (rather than seeking to govern their actual use),[122] the most likely and broadly fair decision-making system would be adherence to standard UN practices: namely, granting each country a vote, possibly combined with special voting rights for the most vulnerable countries (such as the group of least developed countries and/or small island developing states).

'One country one vote' decision rules are already applicable in existing high-stakes global restrictive regimes, such as the Landmines Ban Convention,[123] the Chemical Weapons Convention,[124] and ENMOD.[125] An international agreement on the non-use of solar geoengineering technologies would fit logically into this category of agreements and their decision-making rules.

3.4. Monitoring and Compliance Systems

We turn next to the question of how to monitor the compliance of states and other actors with a potential non-use regime for solar geoengineering. We survey monitoring and compliance mechanisms in existing prohibitory regimes, which range from on-site inspections to interstate consultations to information disclosure systems.

(On-site) monitoring and inspections

One set of procedures includes on-site monitoring and inspections to assess compliance. Prime examples here are the Nuclear Non-Proliferation Treaty[126] and the Chemical Weapons Convention,[127] which have either established specialized agencies or entrusted existing bodies with the task of ensuring implementation and monitoring compliance with regime-specific prohibitions. The International Atomic Energy Agency (IAEA) monitors compliance with the obligations of the nuclear weapons non-proliferation regime through a Safeguards Committee, which is tasked with ensuring oversight of material inventories, monitoring storage areas, and surveying the movement of nuclear materials.[128]

[122] Governing 'use' (deployment) is a different global governance challenge from governing 'non-use' of solar geoengineering. As we discuss here, governing the sustained multi-generational *use* (deployment) of solar geoengineering in a fair and effective manner is implausible, given current global governance architectures, modes of decision-making, and associated geopolitical considerations. However, governing *non-use* and restrictions on technology development in a largely inclusive and potentially effective manner is plausible within existing global governance architectures, should the vast majority of states and the populations they represent decide in favour of this option.

[123] N. 46 above.

[124] N. 48 above, Art. VIII.

[125] N. 75 above.

[126] N. 28 above, Art. III.

[127] N. 48 above, Art. VIII.

[128] IAEA, 'IAEA Safeguards Overview: Comprehensive Safeguards Agreements and Additional Protocols', available at: https://www.iaea.org/publications/factsheets/iaea-safeguards-overview.

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The Chemical Weapons Convention is served by the Organization for the Prohibition of Chemical Weapons (OPCW), which comprises the Convention's COP, a Technical Secretariat, and an Executive Council; it has a mandate to conduct both routine and so-called 'challenge' on-site inspections of country compliance.[129] Any state suspecting that another state is undertaking activities that are contrary to the Convention can trigger a request for an on-site challenge inspection.[130] A three-quarters majority of parties to the Convention is needed for the OPCW to undertake such a challenge inspection.

The OPCW is widely seen by its member states as a useful organizational model for ensuring state compliance with high-stakes international prohibitory regimes in the area of peace and security,[131] also signalled by the fact that it received the Nobel Peace Prize in 2013 for its role in monitoring use as well as destroying stockpiles of chemical weapons during the Syrian conflict.[132] Questions remain, however, about how intrusive on-site inspections should be, relating also to state sovereignty *versus* international geopolitical considerations that shape such decisions, as well as how effective such monitoring systems are in practice.[133]

For a non-use agreement on solar geoengineering, the nature of a (more or less) intrusive on-site monitoring regime would need to be tailored to the object of the prohibitions and be able to address the dual-use challenge relating to research or deployment technologies as well; that is, it must be able to distinguish the restricted from the permitted activity.

Interstate consultation and fact-finding missions

Another model for assessing and ensuring compliance is interstate consultations resulting from complaints of non-compliance brought by individual states against each other. Here, the 1972 Biological Weapons Convention provides an illustrative example.[134] If there is suspicion of non-compliance, a state can lodge a complaint with the UN Security Council. To date, only one state (Cuba) has considered lodging a complaint under this Convention, against the US, although no formal complaint was eventually lodged.[135] Under the Landmines Ban Convention, parties can establish fact-finding missions to address cases of alleged non-compliance with treaty provisions.[136] In the case of solar geoengineering, such fact-finding missions might aid in establishing

[129] N. 48 above, Art. VIII; the OPCW is available at: https://www.opcw.org.
[130] Ibid., Art. VIII.
[131] OPCW Conference of the State Parties, 4th Special Session, 26–28 June 2018, The Hague (The Netherlands), Decision C-SS-4/Dec. 3, 'Addressing the Threat from Chemical Weapon Use', 27 June 2018, available at: https://www.opcw.org/sites/default/files/documents/CSP/C-SS-4/en/css4dec3_e_.doc.pdf.
[132] Nobel Peace Prize announcement of 11 Oct. 2013, available at: https://www.un.org/en/about-us/nobel-peace-prize/opcw-2013.
[133] M.I. Chevrier, 'Compliance Mechanisms and Their Implementation: The Contrast between the Biological Weapons and the Chemical Weapons Conventions' (2020) 27(4–6) *The Non-Proliferation Review*, pp. 475–586, at 482 (examining on-the-ground inspections in Syria, and the pros and cons thereof).
[134] N. 64 above.
[135] See Chevrier, n. 133 above.
[136] N. 46 above, Art. 8.

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whether countries (or private actors in specific jurisdictions) have, for example, released particles into the stratosphere without prior authorization.

Monitoring by independent UN-appointed experts

Inspiration for monitoring compliance with a global prohibitory regime on solar geoengineering can also be drawn from the international human rights regime. This regime features ten treaty bodies of independent experts, who monitor compliance with the nine core human rights conventions and optional protocols with reporting procedures. The interpretation of human rights treaties occurs as part of state reporting through so-called General Comments, or through quasi-judicial processes.[137] To mention one example, the UN Human Rights Committee is the body of independent experts mandated to interpret the provisions of the International Covenant on Civil and Political Rights (ICCPR)[138] and monitor its implementation.[139] The interpretative practice of the UN Human Rights Committee consists of reviews of state reports submitted by parties in accordance with relevant provisions of the Covenant,[140] as well as General Comments, which it may make under Article 40(4) ICCPR. In addition, the Committee interprets ICCPR provisions when reviewing individual complaints under an Optional Protocol,[141] which has led to a significant body of jurisprudence on the attributes of rights protected under the Covenant and on states' obligations to respect and ensure those rights. The ICCPR provides for an interstate complaint procedure under its Articles 41 and 42, subject to the states involved having made a declaration recognizing the competence of the Committee to consider inter-state complaints.

While a non-use agreement on solar geoengineering could replicate some of these institutional arrangements, it could also rely directly on such existing arrangements if these treaties are seen to govern matters relevant to solar geoengineering. The UN Human Rights Committee could, for instance, be called upon if a provision of the ICCPR were breached as a result of the use of solar geoengineering.

In addition to treaty bodies, the UN human rights system includes a human rights body based on the UN Charter, namely, the UN Human Rights Council (HRC), which is a subsidiary body of the UNGA.[142] It consists of 47 UN member states elected

[137] See, e.g., M. O'Flaherty, 'The Concluding Observations of United Nations Human Rights Treaty Bodies' (2006) 6(1) *Human Rights Law Review*, pp. 27–52; N. Jayawickrama, *The Judicial Application of Human Rights Law: National, Regional and International Jurisprudence* (Cambridge University Press, 2002), p. 131. See also T. Meron, *Human Rights Law-Making in the United Nations* (Oxford University Press, 1986), p. 10.

[138] N. 15 above.

[139] Ibid., Arts 28–45.

[140] Ibid., Art. 40(1)(a) requires an initial report to be submitted within one year of ratification of the Covenant and, in Art 40(1)(b), submission of further reports at the request of the Committee. The latter requirement has been interpreted as requiring submission of reports every 5 years; see UN Human Rights Committee, *Yearbook of the Human Rights Committee*, Vol 1, Documents of the 11th to 16th sessions, UN Human Rights Committee, 1981–2, para. 2, available at: https://digitallibrary.un.org/record/83005?ln=es.

[141] New York, NY (US), 16 Dec 1966, in force 23 Mar. 1976, available at: https://www.ohchr.org/sites/default/files/ccpr-one.pdf.

[142] The HRC was created by the UNGA on 15 Mar. 2006 and replaced the former UN Commission on Human Rights: UNGA Resolution 60/215, 'Towards Global Partnership', 22 Dec. 2005, UN Doc. A/RES/60/215, para 1, available at: https://digitallibrary.un.org/record/563759.

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by the UNGA.[143] The HRC is mandated to '[promote] universal respect for the protection of all human rights and fundamental freedoms for all',[144] and to 'promote the effective coordination and the mainstreaming of human rights within the United Nations system'.[145] While the resolutions adopted by the HRC are not legally binding, it could nonetheless be argued that the HRC, as the UN primary human rights body, is in an ideal position to consider what is needed to promote the compliance of states with their obligations under the UNFCCC, including in relation to its objective 'to prevent dangerous anthropogenic interference' with the climate system.[146] Such a consideration by the HRC would include obligations created by a new treaty or a set of soft law norms calling for restrictions on solar geoengineering research or development, given the human rights implications of non-compliance with such obligations.[147] A Special Procedure mandate on solar geoengineering could also be created and executed by the HRC. The effects of solar geoengineering on human rights could also be addressed under existing mandates, such as the mandate of the Special Rapporteur on the promotion and protection of human rights in the context of climate change.[148]

Global clearing house for information sharing

Monitoring compliance with emerging rules or norms on non-use of solar geoengineering could also be facilitated by establishing globally mandated clearing houses of information, through which to enhance transparency about ongoing (unprohibited but potential dual-use) research, patent applications or technology developments. This approach is often used for anticipatory global governance of uncertain and contested risks of novel technologies – for instance, the Biosafety Clearing House established under the global regime governing transboundary transfers of genetically modified organisms[149] – and it is advocated in the case of novel forms of human gene editing.[150]

Summary

In sum, the monitoring of compliance with a global prohibition on development and potential future deployment of solar geoengineering technologies could be organized in a variety of ways, from the establishment of a new specialized agency to reliance on existing treaty bodies and UN organs. Key mechanisms could include monitoring and verification of compliance based on state reporting and interstate complaint procedures, monitoring by independent experts, interstate consultations, or on-site inspections. Ultimately, the success of any monitoring system will depend on the commitment of states

[143] Ibid., para. 7.
[144] Ibid., para. 2.
[145] Ibid., para. 3.
[146] N. 98 above, Art. 2.
[147] M. Wewerinke, 'The Role of the UN Human Rights Council in Addressing Climate Change' (2014) 8(1) *Human Rights and International Legal Discourse*, pp. 10–35.
[148] Available at: https://www.ohchr.org/en/specialprocedures/sr-climate-change.
[149] Cartagena Protocol on Biosafety, n. 60 above. See also Gupta, n. 60 above.
[150] S. Jasanoff & J.B. Hurlbut, 'A Global Observatory for Gene Editing' (2018) 555(7697) *Nature*, pp. 435–7; J.P. Nelson, C.L. Selin & C.T. Scott, 'Towards Anticipatory Governance of Human Genome Editing: A Critical Review of Scholarly Governance Discourse' (2021) 8(3) *Journal of Responsible Innovation*, pp. 382–420.

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to hold each other, as well as relevant private actors, accountable in their efforts to ensure that restrictions or prohibitions relating to non-use of solar geoengineering are respected.

3.5. Consequences of Non-Compliance

When implementing a legal agreement with specific prohibitions and restrictions, it is crucial to consider the consequences of non-compliance or a breach of the treaty. Regarding a global prohibition on the development and deployment of solar geoengineering technologies, the question would not only be what provisions would cover the consequences of non-compliance, but also the obligations of non-complying states to make reparations, which may imply paying for damage that has been caused.

There are two general avenues for securing compliance and preventing unauthorized engagement, as well as addressing consequences of non-compliance: through state responsibility in international law and domestic legislation.

State responsibility

The responsibility of a state in the event of 'wrongful acts' is addressed authoritatively in the International Law Commission's (ILC) Draft Articles on the Responsibility of States for Internationally Wrongful Acts.[151] Under Article 1, 'every internationally wrongful act of a State entails the international responsibility of that State'. Article 2 provides that a state has committed an internationally wrongful act when an action or omission is attributable to the state under international law and when it constitutes a breach of an international obligation of the state. Human rights obligations under existing treaties might be construed as placing obligations on states regarding solar geoengineering, even in the absence of a self-standing treaty on solar geoengineering. The general rule of attribution is contained in Article 4, which provides:

> The conduct of any State organ shall be considered an act of that State under international law, whether the organ exercises legislative, executive, judicial or any other functions, whatever position it holds in the organization of the State, and whatever its character as an organ of the central Government or of a territorial unit of the State.[152]

The type of conduct that is generally attributable to a state as a consequence of these rules includes national legislation and policy, judicial decisions, and administrative measures.[153] In addition to actions, it can also include omissions of required acts.[154] In the

[151] ILC, 'Draft Articles on the Responsibility of States for Internationally Wrongful Acts, with Commentaries' (2001) *Yearbook of the International Law Commission*, Vol. II, Pt Two available at: http://legal.un.org/ilc/texts/instruments/english/commentaries/9_6_2001.pdf.

[152] Ibid., Art. 4(2) (which further clarifies that '[a]n organ includes any person or entity which has that status in accordance with the internal law of the State').

[153] Ibid.

[154] This formulation was used in Art. 1 of the Text of Articles Adopted in First Reading by the Third Committee of the Conference for the Codification of International Law (The Hague, 1930), reproduced in *Yearbook of the United Nations* 1956, Vol. II, Annex 3, pp. 225–6, at 225, available at: https://legal.un.org/ilc/publications/yearbooks/english/ilc_1956_v2.pdf. The Commentaries to the ILC Draft Articles stress that '[c]ases in which the international responsibility of a State has been invoked on the basis of

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case of solar geoengineering, a state could be internationally responsible if, for example, it allowed private actors, explicitly or by omission, to conduct prohibited research on solar geoengineering, or to illegally attempt deployment of the technology.

A non-use agreement on solar geoengineering could provide for different ways to establish such responsibility and request states to cease the breach and make full reparations for any injuries. It could include, for example, a compromissory clause triggering the jurisdiction of the ICJ in the event of an interstate dispute over the implementation and interpretation of a treaty. However, this may not be a time-efficient system of dispute settlement. Additionally, or alternatively, the treaty could include a mechanism similar to that described in Article XII of the Chemical Weapons Convention, whereby a treaty body may ask states to comply with the treaty and escalate the situation to the UNGA or UN Security Council in cases 'of particular gravity'.[155] One could also envisage an international sanction mechanism against a state in breach of its obligations under the treaty, and even the option of adopting sanctions against individuals or companies involved in prohibited conduct.

Domestic legislation

Beyond such international compliance mechanisms, a non-use agreement on solar geoengineering could also include a provision requiring states to have domestic legislation in place to secure compliance. Such legislation could include administrative sanctions, and perhaps even criminal penalties in the case of domestic actors, particularly private companies, engaging in prohibited behaviour. Such legislative arrangements could also include the obligation to pay for the potential harm caused, and measures to ensure that injured parties have a cause of action available to sue responsible actors for damages. A core challenge that arises here is that of attribution, as well as shared understandings of the scope of damages.

In sum, a non-use agreement on solar geoengineering could provide for a comprehensive system of compliance and enforcement, to include international sanctions against states and domestic legislation allowing for administrative and criminal sanctions against private actors. This could include provisions to ensure that responsible actors are held liable for any harm caused by their activities. Such a comprehensive system would provide a strong deterrent against potential breaches of the treaty and ensure that any party to the agreement is held accountable for any violations and the consequences thereof. At the same time, by effecting a broader normative shift in favour of restricting or prohibiting a given activity, such efforts would also exercise a de facto chilling effect on non-participating states and deter their engagement in such activities.

3.6. Regulating Private Actors through International Law

A key challenge for an international prohibitory regime on solar geoengineering would be how to bring the activities of private actors under its purview. If a non-use agreement

an omission are at least as numerous as those based on positive acts, and no difference in principle exists between the two': ILC, n. 151 above, Commentary to Art. 2, p. 35, para. 4. See also J. Crawford, 'The ILC's Articles on Responsibility of States for Internationally Wrongful Acts: A Retrospect' (2002) 96(4) *The American Journal of International Law*, pp. 874–90.

[155] N. 48 above, Art. XII.

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on solar geoengineering were to be effective in regulating the behaviour of states, would it leave the field open to private actors when it comes to (funding or engaging in) research, experimentation, technology development, or even deployment? In the preceding section we considered the potential role of state responsibility and domestic legislation as core means to regulate the behaviour of private actors. Here we briefly consider legal precedents to impose indirect or even direct obligations on private actors in existing prohibitory and restrictive international regimes, as well as broader international legal and policy developments in corporate accountability for human rights and the environment.

Indirect obligations on corporations in international law

Public international law is first and foremost intended to regulate relations between sovereign states. It conceptualizes other actors, such as private companies, as non-state actors, which are generally excluded from the scope of international law and regulated under domestic law. Yet, private actors are also increasingly subject to certain indirect (and even direct) obligations under international law, including within non-use and restrictive agreements.

A useful distinction between direct and indirect obligations of non-state actors, particularly corporations, is advanced by Vazquez,[156] who argues that:

> [international law] address[es] the conduct of corporations … by imposing an obligation on states to regulate non-state actors. … [Thus,] for the most part, international law regulates such non-state actors indirectly. In very few circumstances, international law places obligations on non-state actors directly.[157]

As Vazquez notes,[158] examples of treaties that seek to indirectly regulate corporate conduct include the Convention on Combating Bribery of Foreign Public Officials in International Business Transactions,[159] which requires states to criminalize bribery undertaken by corporations; and the Convention on the Elimination of All Forms of Racial Discrimination, which prohibits race discrimination 'by any persons, group, or organization', including corporations.[160]

In most existing non-use treaties and regimes, however, the private sector is not mentioned, even though the prohibited activities (such as mining in Antarctica or the production of some types of weapon) are potentially lucrative and could be undertaken by companies. This notwithstanding, it can be assumed that private actors, at least indirectly, fall within the scope of these international instruments. For example, were a mining company to start exploring in Antarctica, it would arguably be in breach of the

[156] C.M. Vazquez, 'Direct vs. Indirect Obligations of Corporations under International Law' (2005) 43 *Columbia Journal of Transnational Law*, pp. 927–59.
[157] Ibid., p. 930.
[158] Ibid., p. 934.
[159] Paris (France), 21 Nov. 1997, in force 15 Feb. 1999, available at: https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0293.
[160] New York, NY (US), 21 Dec. 1965, in force 4 Jan 1969, available at: https://www.ohchr.org/sites/default/files/cerd.pdf.

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Protocol on Environmental Protection to the Antarctic Treaty, even though mining companies are not mentioned in this instrument.[161]

In this respect, an important precedent is offered by the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal.[162] In its Article 2, the treaty explicitly mentions the private sector, even though it creates obligations only for state parties to regulate private activities indirectly.[163] Following this model, a non-use agreement on solar geoengineering could place indirect obligations on the private sector by requiring states to legislate to prohibit or limit private development or deployment of solar geoengineering technology. Monitoring, enforcement, and possible liability mechanisms relating to these obligations would then need to be established under domestic law.

Direct obligations on corporations in international law

It is also increasingly feasible to consider placing direct obligations on the private sector alongside state obligations in international law. This would be possible because corporations already have some direct general obligations under international law, even in the absence of specific treaty provisions. Notably, companies have the obligation not to commit international crimes, and they fall within the general scope of the Geneva Conventions and international humanitarian law.[164] In other words, direct corporate obligations under international law are possible.

Certain treaties, and in particular Part XI of UNCLOS,[165] have already set up direct, general obligations for 'juridical persons' (such as private companies) not to damage the environment and human life.[166] Those precedents are important in that they create a restrictive regime and establish the principle of direct obligations for companies, while admittedly leaving it mostly to states to monitor and enforce these obligations.

Recent international soft law developments further reinforce this principle that companies may be subject to direct obligations. Several soft law instruments establish corporate responsibility for human rights, such as the UN Guiding Principles on Business and Human Rights[167] and the revised Organisation for Economic Cooperation and Development (OECD) Guidelines for Multinational Enterprises on Responsible

[161] N. 18 above. Art. 7 only states that '[a]ny activity relating to mineral resources, other than scientific research, shall be prohibited'.

[162] Basel (Switzerland), 22 Mar. 1989, in force 5 May 1992, available at: http://www.basel.int.

[163] Ibid., Art. 2(14)–(19).

[164] On this see A. Clapham, *Human Rights Obligations of Non-State Actors* (Oxford University Press, 2006), p. 79.

[165] N. 20 above.

[166] Ibid. See also the International Tribunal for the Law of the Seas (ITLOS), *Responsibilities and Obligations of States Sponsoring Persons and Activities with respect to Activities in the Area*, Case No. 17, Advisory Opinion of 1 Feb. 2011, (2011) *ITLOS Reports*, p. 10. On this point see also N. Bernaz & I. Pietropaoli, 'Developing a Business and Human Rights Treaty: Lessons from the Deep Seabed Mining Regime under the United Nations Convention on the Law of the Sea' (2020) 5(2) *Business and Human Rights Journal*, pp. 200–20.

[167] Endorsed by the UN HRC in Resolution 17/4, 16 June 2011, available at: https://www.ohchr.org/sites/default/files/documents/publications/guidingprinciplesbusinesshr_en.pdf.

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Business Conduct.[168] These developments have had a profound impact on discussions about acceptable corporate behaviour in a globalized economy, and have even served as interpretative tools in a Dutch case against oil multinational company Royal Dutch Shell.[169] In this case, a Dutch court considered the UN Guiding Principles on Business and Human Rights as 'the global standard of expected conduct for corporations' in the intertwined areas of human rights, the environment and climate.[170]

In sum, considering the context of enhanced corporate accountability, the potential contribution of the private sector to developing solar geoengineering technology and the potentially severe impacts of deploying it, it would be logical for a non-use regime on solar geoengineering to create not only indirect but also direct obligations on the private sector.

4. Conclusion

Since 2022, more than 490 academics from 61 countries and over 1,900 civil society organizations have supported a global call for an International Non-Use Agreement on Solar Geoengineering, setting the scene for a broader debate on restricting the development of such risky technologies with planetary impact.[171] So far, however, the possible legal structure and design principles underpinning such a non-use or restrictive regime have remained unexplored.

We have addressed this research gap by examining an array of existing prohibitory international regimes that ban or restrict the use of certain substances, technologies, or activities. Our analysis suggests that there are numerous approaches on which governments could rely to restrict solar geoengineering at various stages of research, development, and potential future deployment and use, should they choose to do so. There also exist a plethora of options for institutional arrangements and mechanisms for monitoring compliance and sanctioning non-compliance with non-use obligations. At the same time, our analysis shows that there is no blueprint in international law for a non-use agreement on solar geoengineering. Instead, a prohibitory regime on solar geoengineering would need to be a *sui generis* agreement, which would resemble existing agreements in some ways but would in its entirety be a novel type of regime.

[168] Adopted 8 June 2023, available at: https://doi.org/10.1787/81f92357-en. See also OECD, *Guiding Principles on Business and Human Rights: Implementing the United Nations 'Protect, Respect and Remedy' Framework* (OECD, 2011).

[169] *Milieudefensie et al.* v. *Royal Dutch Shell Plc*, District Court of the Hague, 26 May 2021, ECLI:NL:RBDHA:2021:5337, English translation ECLI:NL:RBDHA:2021:5339, available at: https://uitspraken.rechtspraak.nl/inziendocument?id=ECLI:NL:RBDHA:2021:5339 (*Milieudefensie* v. *Shell*).

[170] Ibid., para. 4.4.13. See also C. Macchi & J. van Zeben, 'Business and Human Rights Implications of Climate Change Litigation: *Milieudefensie et al.* v. *Royal Dutch Shell*' (2021) 30(3) *Review of European, Comparative, and International Environmental Law*, pp. 409–15; see also B. Mayer, 'The Duty of Care of Fossil-Fuel Producers for Climate Change Mitigation: *Milieudefensie* v. *Royal Dutch Shell*, District Court of The Hague (The Netherlands)' (2022) 11(2) *Transnational Environmental Law*, pp. 407–18; L. Burgers 'Response: An Apology Leading to Dystopia: Or, Why Fuelling Climate Change Is Tortious' (2022) 11(2) *Transnational Environmental Law*, pp. 419–31; and B. Mayer, 'Judicial Interpretation of Tort Law in *Milieudefensie* v. *Shell*: A Rejoinder' (2022) 11(2) *Transnational Environmental Law*, pp. 433–36.

[171] Biermann et al., n. 9 above.

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Furthermore, and importantly, our analysis suggests that international regimes can be designed to prohibit or restrict specific harmful activities or technologies *without* placing undue restrictions on legitimate and desirable activities. Despite global bans on the development of chemical or biological weapons, for example, research and innovation in the chemical or pharmaceutical industries has continued apace, and research on new chemicals and new medicines has flourished for decades, despite targeted restrictions on the weaponized use of such knowledge.

Efforts can be made to ensure the same outcome for a restrictive regime on solar geoengineering. Here, too, various legal techniques would be available to prohibit the development of capacities to engage in solar geoengineering *without* limiting lawful and important research programmes in climate science, vulcanology, stratospheric research, or the social sciences and humanities. Even modelling of solar geoengineering in the laboratories of climate scientists could continue, depending on the level of restrictions that governments choose to apply – as long as the intentional development of solar geoengineering technologies remains clearly and effectively prohibited through public oversight and control.

The exact legal form of an International Non-use Agreement on Solar Geoengineering will need to be determined through international negotiations. These typically would be initiated by an international organization or a coalition of governments. Given the planetary-scale nature of the threat posed by potential future use of solar geoengineering, a resolution by the UNGA could be a logical avenue for initiating discussions on such a non-use agreement. Other institutions, such as the UN Environment Assembly, could also be initiators. Given the planetary-scale nature of the issue, a joint initiative by a coalition of countries cutting across the global north and the global south might be an effective and legitimate way forward, for example, through a joint declaration by the EU and the African Union.

Legally and politically, to be effective, a non-use agreement on solar geoengineering would not need to be universally accepted, at least not at the outset. For example, parties to such an agreement could stipulate measures to restrict the ability of third parties to act in a manner contrary to its provisions.[172] Of more importance, however, would be the overall (normative and political) impact of a non-use agreement, even if some powerful countries choose to remain outside it. If a non-use agreement on solar geoengineering finds support from most countries, including a large majority of developing countries, it becomes more challenging for non-participating states to continue to invest unilaterally in major research or technology development programmes. For the same reason, even soft-law mechanisms – such as a non-binding UNGA resolution calling for the non-use of solar geoengineering – could be effective in disincentivizing technology development programmes. Such declarations could signal not only to states but also to private foundations and wealthy individuals that solar geoengineering stands

[172] An example is the Montreal Ozone Protocol (n. 84 above) where trade in ozone depleting substitutes or viable substitutes with non-parties is prohibited, providing a potential incentive for those outside a regime to join it. This furthers the objectives of a given treaty (in this case, to prohibit or restrict trade in ozone depleting substances) by placing obligations on those who *have* voluntarily chosen to be part of an international regime not to engage with those who remain outside it.

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little chance of support in international institutions. In short, a non-use agreement could be realized in a variety of ways.

To conclude, while there is no blueprint in international law for the design of a possible future non-use agreement on solar geoengineering, our analysis shows that there are numerous specific elements in existing prohibitory and restrictive regimes from which governments could draw inspiration, should they choose to restrict or prohibit the development of solar geoengineering technologies. As a next step, and drawing on this discussion, legal scholars and political decision makers can devise a proposed draft treaty, if this is desired.

More broadly, we show here that a non-use agreement on solar geoengineering is legally feasible and would be an addition to an already large body of internationally negotiated treaties by which governments seek to prohibit development of technologies, substances, or activities that would be very challenging to control if deployed, and that are widely seen as dangerous and undesirable. A future research agenda is then also to further elaborate on the many and diverse ways in which a 'non-use' norm could be developed, diffused, and institutionalized globally, through both legal and political means.

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