European Journal of Risk Regulation (2025), 1–12
doi:10.1017/err.2025.10048

CAMBRIDGE UNIVERSITY PRESS

ARTICLE

Solar Geoengineering Governance: A Fragmented Institutional Landscape Covering Multi-Dimensional Impacts

Dana Ruddigkeit[1], Heleen Bruggink[2] and Aarti Gupta[2,3]

[1]German Environment Agency, Dessau-Roßlau, Germany, [2]Wageningen University, Wageningen, The Netherlands and [3]Climate Change Leadership Group, Uppsala University, Uppsala, Sweden
Corresponding author: Dana Ruddigkeit; Email: dana.ruddigkeit@uba.de

Abstract

A widely made claim in academic scholarship is that the governance of solar geoengineering is characterised by gaps in international law and the absence of regulatory mechanisms. This article presents a more nuanced perspective on this claim. Instead of focusing on one comprehensive regime to govern solar geoengineering (whether its use or its non-use), we adopt a multi-dimensional impact approach to consideration of solar radiation modification (SRM) technologies and their governance. We outline the diverse array of adverse impacts that any SRM governance regime would need to contend with, and map how many of these impacts fall within the purview of existing international institutions and obligations. We conclude that any future SRM governance regime would need to build upon or at least not contravene these existing obligations. While our analysis thus modifies the claim of gaps in international law relating to SRM governance, it also suggests that the fragmented yet comprehensive coverage of diverse impacts does not mean that global coordination to govern deployment of SRM is already in place. Instead, the fragmented web of institutions and principles that exists provides room largely for restrictive SRM governance, in order to prevent adverse impacts within core areas of concern.

Keywords: fragmentation; global governance; non-use; solar geoengineering; solar radiation modification

I. Introduction

Solar geoengineering, also called solar radiation modification (SRM), refers to speculative methods designed to intentionally alter the shortwave radiative budget of the Earth, seeking to mitigate (global) warming.[1] One specific method, stratospheric aerosol injection (SAI)—the massive injection of reflective particles into the stratosphere to reflect a portion of incoming sunlight back out into space and thus create a cooling effect —receives significant attention.[2] Yet SAI would have planetary-scale, unequally distributed impacts on the climate and associated food and other systems, raising the question of how such planetary scale impacts could be governed.

[1] National Academies of Sciences, Engineering, and Medicine (NASEM), *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (National Academies Press 2021) 21.

[2] ibid, 66.

A long-standing claim in the governance literature is that solar geoengineering operates in a largely ungoverned space, lacking shared norms, institutional arrangements and formal rules or regulations. Many scholars point to the existence of gaps in international law and highlight the absence of adequate regulatory frameworks to effectively govern these emerging technologies.[3] This notion of (legal) "gaps" warrants closer scrutiny.

In this article, we begin from the point of departure that governing SRM poses a multidimensional governance challenge, given that a diverse array of impacts (on the atmosphere, on the marine environment, on biodiversity, on geopolitics and on human security, among others) would need to be considered. As such, our core aim here is to map the existing web of international legal obligations and institutions that have bearing on this diverse and multifaceted set of impacts associated with solar geoengineering. Our analysis suggests that the existing web of international obligations offers a foundational framework that addresses many of the potential impacts associated with deployment of solar geoengineering. As such, our analysis here challenges the characterisation in much academic literature of a persisting "gap" in global governance of SRM.

We proceed as follows. The next section II considers the wide array of impacts that would need to be governed in the event of any future use of solar geoengineering, and maps existing obligations and expertise that already address these impacts. We then consider in section III the implications of this fragmented institutional architecture for governing use versus non-use of SRM. We conclude that the prospects for restrictive global governance of SRM are already present within this existing fragmented architecture.

II. Mapping multi-dimensional impacts and associated institutions

SRM is associated with numerous risks and can affect various areas of international politics and various objects of protection covered by different international law regimes and institutions. Hereby, different scientific disciplines and expert communities are involved. Below we map some of these impact areas and associated relevant legal obligations.

1. The impact on the ozone layer and the ozone treaties

The deployment of SRM would have impacts on the chemistry and dynamics of the stratosphere, with potentially adverse effects. For instance, stratospheric aerosol injection, particularly using sulphate aerosols, may lead to increased stratospheric ozone depletion.[4] Effects on ozone due to aerosol injections are not limited to sulphate aerosols. Other aerosols could also impact stratospheric ozone via "changes in heterogeneous chemistry and dynamics and transport."[5] The specific extent of these effects remains uncertain,

[3] See JA Flegal, AM Hubert, DR Morrow and JM Cruz, "Solar Geoengineering: Social Science, Legal, Ethical, and Economic Frameworks" (2019) 44/1 Annual Review of Environment and Resources 399, 412; K Brent, J McGee and J McDonald, "The Governance of Geoengineering: An Emerging Challenge for International and Domestic Legal Systems" (2015) 24/1 The Journal of Law and Information Science 25–6; C Armeni and C Redgwell, "International legal and regulatory issues of climate geoengineering governance: rethinking the approach" (2015) 21 *Climate Geoengineering Governance Working Paper* 6–8; A Strong, "Toward an International Geoengineering Agreement: The Promises (and Pitfalls) of Negotiating a Convention on Global Climate Interventions" (2011) *Papers on international environmental negotiation, Volume 18: Next generation of environmental agreements* 27, 23, 32, 33; T Kuokkanen and Y Yamineva, "Regulating Geoengineering in International Environmental Law" (2013) 3 Carbon and Climate Law Review 161, 165.

[4] World Meteorological Organization (WMO), *Scientific Assessment of Ozone Depletion*, GAW No. 278 (Geneva: WMO 2022) 27; United Nations Environment Programme (UNEP), *One Atmosphere: An Expert Review on Solar Radiation Modification Research and Deployment* (Nairobi: UNEP 2023) 18.

[5] WMO, *supra* note 4, 45.

https://doi.org/10.1017/err.2025.10048 Published online by Cambridge University Press

partly due to factors such as injection strategy. In any case, to assess these specific effects of SRM on ozone and other atmospheric processes, expertise in atmospheric dynamics is required, also to understand the implications of these for existing international obligations that may address these effects.

The treaty texts of the 1985 Vienna Convention for the Protection of the Ozone Layer and its 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, both ratified by 198 parties, demonstrate considerable relevance to solar geoengineering.[6] The potential impact of use of SRM on ozone could bring such activities in conflict with the obligations in Article 2 of the Vienna Convention, which require states to take measures to protect the environment and human health against "adverse effects" resulting, or likely to result, from human activities that modify the ozone layer.[7] Further, Article 3 of the Vienna Convention obliges states to undertake and cooperate in research and scientific assessments related to activities that may affect the ozone layer. These obligations extend not only to understanding climate impacts,[8] but also to the exchange of socio-economic and commercial information,[9] as well as legal information concerning laws, bilateral agreements, administrative measures and patent availability.[10] As such, the Vienna Convention obliges states to assess solar geoengineering techniques and their geophysical and chemical impacts on the atmosphere and report on socio-economic and legal developments. This is underlined by the observed practices of the regime: the 2022 report by the UN-backed Scientific Assessment Panel to the Montreal Protocol included a chapter dedicated to stratospheric aerosol injection and its potential impacts on ozone.[11] Later that year, the Parties to the Protocol acknowledged the need for further assessment while "*[n]oting* also the potential for negative effects that stratospheric aerosol injection may have on the ozone layer."[12] These obligations show that there is an institution in place that is legally mandated to assess and guide these central impacts of solar geoengineering.

2. Weather and climate impacts and the WMO

The injection of aerosols in the stratosphere would impact weather and climate patterns with potentially adverse effects. An obvious impact is the potential reduction in global temperature, which would be unevenly distributed both spatially and temporally.[13] Moreover, the implementation of SRM methods would likely result in alterations in the

[6] Vienna Convention for the Protection of the Ozone Layer (adopted 22 March 1985, entered into force 22 September 1988) 1513 UNTS 293; Montreal Protocol on Substances that Deplete the Ozone Layer (adopted 16 September 1987, entered into force 1 January 1989) 1522 UNTS 3.

[7] For a more detailed analysis, see R Bodle, G Homan, S Schiele, and E Tedsen, *The Regulatory Framework for Climate-Related Geoengineering Relevant to the Convention on Biological Diversity*, CBD Technical Series No. 66 II (Montreal: Secretariat of the Convention on Biological Diversity 2012) 128–9. Art. 2 (2)(b) reads "to control, limit, reduce or prevent human activities under their jurisdiction or control should it be found that these activities have or are likely to have adverse effects resulting from modification or likely modification of the ozone layer."

[8] See Vienna Convention, *supra* note 6, Annex I.

[9] ibid, Annex II, paragraph 5.

[10] ibid, Annex II, paragraph 6.

[11] WMO, *supra* note 4.

[12] Montreal Protocol on Substances that Deplete the Ozone Layer, Decision XXXV/4: Stratospheric aerosol injection and protection of the ozone layer <https://ozone.unep.org/treaties/montreal-protocol/meetings/thirty-fifth-meeting-parties/decisions/decision-xxxv4-stratospheric-aerosol-injection-and-protection-ozone-layer>.

[13] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (UK and NY: Cambridge University Press 2021) 104 <https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport.pdf>.

atmospheric hydrological cycle that may result in a decrease in global mean precipitation[14] and alter regional precipitation patterns.[15]

The World Meteorological Organization (WMO), with 187 Member States and 6 Member Territories, is one of the rare examples of an international organisation in international environmental governance that not only assesses impacts on weather, climate, meteorology, hydrology and related environmental issues, but also promotes international coordination in these areas. Article 2 of the Convention of the World Meteorological Organization, adopted in 1947, states that one of the purposes is "to further the application of meteorology to aviation, shipping, water problems, agriculture and *other human activities*."[16] As such, Article 2 suggests that the WMO is the primary international institution for assessing the impacts of weather dynamics and climate on human life. Since SRM intends to modify weather and climate, the WMO thus has the responsibility to evaluate the central impact of solar geoengineering. Importantly, however, and in terms of governance mandate, no regulatory capacity beyond describing and assessing the weather has been conferred on the WMO.

Beyond the legal finding that the WMO is mandated to assess the impact of solar radiation modification on the weather, it should be emphasised that in the WMO, the necessary expertise to assess and evaluate weather and climate dynamics is present.[17] Consequently, and not only from a legal but also from a functional perspective, any decision-making scheme on deployment would have to integrate this knowledge or duplicate it, risking incoherencies.

3. Biodiversity impacts and the mandate and practice of the CBD

Ecosystems and biodiversity may be adversely impacted by both the implementation and sudden termination of solar geoengineering. Deployment of SRM may influence global and regional weather and climate changes, hydrological cycles and soil and vegetation, potentially disrupting ecosystems and negatively impacting biodiversity.[18] Abrupt termination of any deployment scheme could lead to rapid and unprecedented increases in ocean and land temperatures, which may trigger unparalleled climate changes that may result in substantial losses of biodiversity.[19]

The international institution mandated to assess the ecosystem impacts related to solar geoengineering is the 1992 Convention on Biological Diversity (CBD).[20] The CBD enjoys near-universal participation, with 196 states having ratified it, except for the United States, which has only signed. Nonetheless, the United States did not submit a formal note of non-ratification and remains an active observer at the annual Conferences of the Parties (COP) to the CBD. The objective of the CBD is to conserve biological diversity and its sustainable use. Furthermore, Article 3 of the Convention states that member states have

[14] ibid, 105.

[15] UNEP, *supra* note 4, 32.

[16] Convention of the World Meteorological Organization (adopted 11 October 1947, entered into force 23 March 1950) 77 UNTS 143, emphasis added.

[17] Expertise of WMO and IPCC is overlapping. We are focusing in this short article on WMO since it is a subject of international law, having rights and duties on its own.

[18] Secretariat of the Convention on Biological Diversity, *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters*, CBD Technical Series No. 66 (Montreal 2012); IPCC, *Global Warming of 1.5°C: An IPCC Special Report* (2018) Ch. 4.3.8; CH Trisos et al., "Potentially dangerous consequences for biodiversity of solar geoengineering implementation and termination" (2018) 2/3 Nature Ecology & Evolution 475–482; K Dagon and DP Schrag, "Quantifying the effects of solar geoengineering on vegetation" (2019) 153 Climatic Change 235–251; PL Zarnetskea et al., "Potential ecological impacts of climate intervention by reflecting sunlight to cool Earth" (2021) 118/15 Proceedings of the National Academy of Sciences of the United States of America.

[19] Trisos et al., supra note 18; IPCC, supra note 18.

[20] Convention on Biological Diversity (adopted 5 June 1992, in force 29 December 1993) 1760 UNTS 79.

"the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction".[21] Areas beyond national jurisdiction are global commons such as high seas, the atmosphere and space, thus relevant for solar geoengineering. Moreover, the preambular paragraphs underline that "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimise such a threat" and that "it is vital to anticipate, prevent and attack the causes of significant reduction or loss of biological diversity *at source*".[22] In Article 7, states further commit themselves to monitor processes and activities that are likely to have adverse effects on the "conservation and sustainable use of biological diversity."[23] Given the likely impacts of solar radiation modification on biodiversity, member states are obliged under the CBD to monitor but also avoid or minimise adverse impacts on biodiversity.

This interpretation is reinforced in the observed practices of the regime. Consistent with its mandate, the 2010 decision X/33 paragraph 8(w)—reaffirmed in 2012, 2016 and 2024—invites parties to ensure that "no climate-related geo-engineering activities that may affect biodiversity take place" under the provisos that the restriction applies until "an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts."[24] Although the decision is not directly legally binding on states, it is seen as a "normative precedent"[25] and represents a consensus decision of all member states that interpret the binding treaty. Although the United States did not ratify the CBD, it should be noted that it did not object to references to CBD X/33 decisions at the United Nations Environment Assembly (UNEA) negotiations on SRM in 2019 and 2024. Even when assuming a lack of United States engagement in the CBD, any new multilateral treaty on SRM cannot be designed without taking into account existing CBD obligations that apply to its very large number of Parties. Moreover, the global expertise on biodiversity represented in the CBD cannot simply be overlooked or duplicated by a new SRM regime—this functional perspective is further emphasized in Section III.1 below. While the CBD has a broad mandate to assess and monitor activities that have an impact on biodiversity and to set guidelines to do so, it does not have effective control and regulatory mechanisms in place to govern SRM use.

4. Security and geopolitical impacts: UNSC and ENMOD

Solar geoengineering also presents various security and geopolitical risks. The unilateral deployment of SRM could have adverse impacts on the territories, economies and security of other states. Such unilateral deployment, involving a state or group of states deploying the technology without the consent or approval of the international community, therefore, represents a significant security concern.[26] Unlike current emissions of

[21] ibid, Article 3, 5.

[22] ibid, 2, emphasis added. Given that the causes of biodiversity loss have to be tackled "at source", this precludes inclusion of SRM as a protection measure under the CBD and the precautionary principle.

[23] ibid, Article 7, 7.

[24] Convention on Biological Diversity, Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its tenth meeting, UNEP/CBD/COP/DEC/X/33 (2010).

[25] Royal Society, *Solar radiation management: the governance of research* (2011) 32; German Environment Agency, *Solar Radiation Modification - Concepts, Risks and Governance of intervention in the global climate system through solar geoengineering* (Umweltbundesamt 2025) 41.

[26] EL Chalecki and LL Ferrari, "A new security framework for geoengineering" (2018) 12/2, Strategic Studies Quarterly, 82–106; O Corry, "The international politics of geoengineering: The feasibility of Plan B for tackling climate change" (2017) 48/4, Security Dialogue, 297–315; BK Sovacool, C Baum and S Low, "The next climate war?

greenhouse gases, the deployment of SAI would be intentional and could be perceived as deliberate and politically motivated acts of aggression.[27] Some have also raised concerns about the potential militarisation of solar geoengineering due to the involvement of military and security institutions in research, the integration of militarisation assumptions in deployment scenarios, and the strategic potential of solar geoengineering in geopolitics, energy and climate change interlinkages.[28]

Various treaties and international institutions are potentially relevant for addressing security aspects of solar geoengineering. The United Nations Security Council (UNSC), operating within a framework of universal applicability to all UN member states, holds the "primary responsibility for the maintenance of international peace and security," as specified in Article 24 of the UN Charter.[29] It can determine "threats to the peace" and take measures under Articles 41 and 42 to maintain peace.[30] Thus, the UNSC could impose sanctions in cases of unilateral deployment if viewed as a threat to international peace and security. It is important to acknowledge that practical implementation might be hindered by factors such as veto rights and lack of enforcement mechanisms.

Another potentially relevant regime is the 1977 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), with seventy-eight parties, including China and the US.[31] The main substantial obligation enshrined in the text of the 1977 treaty is not to undertake military or other hostile use of environmental modification techniques having severe, widespread, and long-lasting effects.[32] Thus, "hostile" deployment of solar geoengineering, causing such outcomes, is prohibited. The line between peaceful and hostile use remains debated.[33] Since ENMOD was agreed upon in an arms control context during the Cold War, some argue that only acts in "armed conflicts" are covered by ENMOD.[34] However, since the methods and techniques of warfare are changing rapidly and do not only include traditional weapons, discussions are ongoing to broaden the concept of "armed conflict" to include new technologies.[35] Moreover, in case the militarisation of solar geoengineering technologies proceeds, as some view as likely,[36] the interpretation of "hostile use" could well encompass SRM deployment scenarios, even if no weapons are deployed in a conventional manner. While both the UNSC and ENMOD are not entirely adequate for preventing or managing potential

Statecraft, security, and weaponization in the geopolitics of a low-carbon future" (2023) Energy Strategy Reviews, 45, 101031.

[27] Human Rights Council Advisory Committee, *Impact of new technologies intended for climate protection on the enjoyment of human rights* A/HRC/54/47 (2023) 7, 9.

[28] J Stephens and K Surprise, "The hidden injustices of advancing solar geoengineering research" (2020) 3 Global Sustainability 4; K Surprise, "Geopolitical ecology of solar geoengineering: from a 'logic of multilateralism' to logics of militarization." (2020) 27/1 Journal of Political Ecology 213–35.

[29] Charter of the United Nations (adopted 26 June 1945, entered into force 24 October 1945) 1 UNTS XVI, Art. 24.

[30] ibid, Art. 39.

[31] Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (adopted 10 December 1976, entered into force 5 October 1978) 1108 UNTS 151.

[32] ibid, Art. 1(1). The terms "widespread" "long-lasting" and "severe" are not defined in the treaty text.

[33] J McGee, K Brent, J McDonald and C Heyward, "International Governance of Solar Radiation Management: Does the ENMOD Convention Deserve a Closer Look?" (2020) 14/4 Carbon and Climate Law Review 294–305.

[34] R Bodle et al., "Options and Proposals for the International Governance of Geoengineering" (2014) 57 <https://www.umweltbundesamt.de/publikationen/options-proposals-for-the-international-governance>; EA Parson, "Climate Engineering in Global Climate Governance: Implications for Participation and Linkage" (2014) Transnational Environmental Law 89, 96.

[35] K Klonowska, "Shifting the narrative: not weapons, but technologies of warfare" (Humanitarian Law & Policy Blog, 20 January 2022), available at <https://blogs.icrc.org/law-and-policy/2022/01/20/weapons-technologies-warfare/>.

[36] Human Rights Council Advisory Committee, *supra* note 27, 7: "Solar radiation modification projects would be intentional and therefore could be seen as deliberate and politically hostile acts"; J Stephens and K Surprise, *supra* note 28, 4; K Surprise, *supra* note 28, 213.

conflicts arising from deployment, these existing frameworks still offer some relevance in addressing security aspects and may restrict some solar geoengineering activities.

5. Impacts on human rights and human rights law

Human rights law becomes relevant when specific solar geoengineering activities violate specific human rights. Any solar geoengineering deployment scheme would need to comply with existing human rights obligations and standards. The Universal Declaration of Human Rights (UDHR) provides a foundational normative framework for human rights, with many of its provisions reflected in binding international and regional human rights instruments, such as the International Covenant on Economic, Social and Cultural Rights (ICESCR), the International Covenant on Civil and Political Rights (ICCPR), the African Charter on Human and Peoples' Rights (ACHPR), the European Convention on Human Rights (ECHR) and the American Convention on Human Rights (ACHR).

Some have already pointed to solar geoengineering activities as presenting a significant risk of violating specific human rights – some of which recognised in the above mentioned instruments – such as the right to a clean, healthy, and sustainable environment, the right to an adequate standard of living, the right to life, and the rights associated with consultation and free, prior, and informed consent.[37] These and other potential violations to human rights from any future use of SRM have also been recognised by the UN Human Rights Council Advisory Committee, which noted that "the development of any such technologies and policies to support them would not be in accordance with the protective standards of the human rights regime."[38] Although not all relevant human rights instruments and protective standards noted above are binding in a strict legal sense, principles of international law deriving from human rights law and protective standards—as well as environmental law—remain applicable to any assessment of, or decision-making on, solar geoengineering technologies. In this context, the human rights regime provides important tools for assessing and monitoring this key impact area of any future SRM governance regime.[39]

We have outlined several existing regimes in this section, with relevance for governing potential impacts associated with solar geoengineering (see Figure 1).

Our analysis is not exhaustive, given the existence of over 1300 multilateral environmental agreements, many of which could also be affected by (unilateral or multilateral) solar geoengineering activities.[40] Our discussion above does highlight, however, that most of the core impact areas linked to SRM are already covered by a wide array of international legal obligations, even if solar geoengineering is not explicitly mentioned or directly regulated as a technology or practice herein.

While certain governance "deficits" are present in this fragmented institutional landscape, particularly regarding key regime attributes such as lack of universal participation, effective decision-making or enforcement capacities, such deficits are

[37] The Republic of Vanuatu, *Written Statement submitted by the Republic of Vanuatu, Obligations of States in Respect of Climate Change (request for advisory opinion)* International Court of Justice (March 21, 2024) 284–86.

[38] Human Rights Council Advisory Committee, *supra* note 27, 17.

[39] A Gupta et al., "Towards a non-use regime on solar geoengineering: Lessons from international law and governance" (2024) Transnational Environmental Law 1–32.

[40] The United Nations Environment Programme (UNEP) is also of key relevance in addressing impacts of SRM. Other relevant frameworks include the United Nations Convention on the Law of the Sea (UNCLOS), the Antarctic Treaty System, the United Nations Convention to Combat Desertification (UNCCD), the Convention on Long-Range Transboundary Air Pollution (LRTAP) as a regional regime on air pollution, as well as habitat-specific regimes, like the Framework Convention on the Protection and Sustainable Development of the Carpathians, or many others.

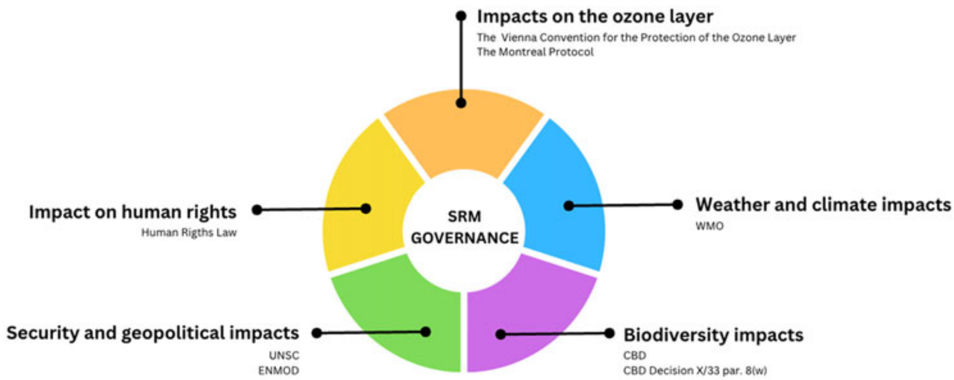

Figure 1. A fragmented institutional architecture with extensive coverage of SRM impact areas.

common to many international environmental regimes,[41] and are also likely to hold for any future new SRM regime, should one be devised. Distinguishing such "deficits" from the notion of governance "gaps" is important in our view.

In contrast to deficits, by governance gaps, we understand here a gap in coverage of specific SRM impacts. A governance gap would imply an absence of regulations, norms or institutional coverage of key impact areas associated with SRM. As our analysis above has shown, multiple areas of SRM-related impacts are already covered within the international legal architecture. It is in this light that we argue that solar geoengineering, when approached from a multi-dimensional impact perspective, as we do in this article, is not an entirely ungoverned space. Hence, we challenge the notion of governance "gaps," given that a diverse array of impacts of SRM are already covered by existing international regimes, which cannot be overridden or ignored. As such, this web of relevant international obligations, even if scattered, would need to be leveraged in any future governance of SRM, to which we turn next.

III. Accounting for what exists: leveraging a fragmented architecture

None of the entities outlined in the previous section is on its own sufficient to assess multiple impacts of SRM or holistically govern its use or non-use. This raises the question: Can these elements be effectively coordinated and harmonised or integrated into a new SRM governance framework? Addressing this question comprehensively is outside the scope of this short article. Below, we offer a few reflections on the legal guidelines, the advantages and disadvantages associated with this fragmented institutional landscape, and what prospects it offers for governing non-use versus use of SRM.

1. A fragmented architecture: implications for governing SRM non-use

In terms of a coordinated response for a restrictive, non-use regime on SRM, this fragmented institutional landscape does not pose an insurmountable hurdle. The legal obligation guiding this coordination is the principle of systemic integration in Article 31(3)(c) of the Vienna Convention on the Law of Treaties (VCLT). This article instructs treaty interpreters to take into account "any relevant rules of international law applicable

[41] See for a discussion of such aspects as deficits rather than gaps, for example, P Pattberg and K Bäckstrand, "Enhancing the achievement of the SDGs: lessons learned at the half-way point of the 2030 Agenda" (2023) 23, Int Environ Agreements 107–14.

in the relations between the parties."[42] Accordingly, any new SRM regime would have to take into account the treaties, norms and obligations outlined in Section II.

This legal obligation is not only relevant for norm collisions and normative divergencies between regimes in a strictly legal sense, but also for operations and assessments within a regime.[43] Since any formal or informal decision or operational application of a treaty inevitably relies on scientific and operational assessments conducted under its mandate, coordinating research across these is proposed as one tool to manage legal fragmentation.[44] From this, it follows that (scientific) assessments conducted within one regime and from a specific scope and mandate must not draw any operative conclusion on SRM measures without taking into account the assessments of adjacent regimes. Hereby, "taking into account" would be more than mentioning a finding and then setting it aside. Setting aside or prioritising impact dimensions of neighbouring regimes without mutual referencing and substantial reasons would not be in line with the principle of systemic integration.

The more restrictive the mandate of any new SRM governance regime, the easier it will be to meet the requirements of Article 31.3.c VCLT on systemic integration. This is because only assessments and decisions that are directed to active measures and, therefore, actively risk frustrating the goals of another regime can trigger the legal obligations of systemic integration. In this light, the existing web of obligations to avoid or minimize diverse potential adverse impacts of SRM will result in restricting or ruling out some (or all) SRM deployment options. In theory, fragmentation may block the possibility of effective decision-making within a single new SRM regime. But instead of coming to quick conclusions at this point, it will be illuminating to have a closer look at the literature on fragmentation of international law. Early literature on fragmentation focused on pointing out the negative effects of fragmentation, such as producing conflicts and inefficiencies due to diverging international obligations.[45] This corresponds to most of the findings in the SRM governance literature, which suggest governance gaps due to incoherence and incomprehensiveness of the existing governance landscape.[46]

However, the report of the Study Group of the International Law Commission on fragmentation in international law does not suggest the need to overcome fragmentation, but it rather analyses how to deal with it.[47] In line with this, a new generation of

[42] Vienna Convention of the Law of Treaties (adopted 23 May 1969 entered into force 27 January 1980) 1155 UNTS 331. Regarding the criterion "in the relations between the parties" in case of multi- or plurilateral treaties not having identical groups of member states, which cannot be discussed here in detail, Art. 41 of the VCLT is instructive.

[43] M Koskenniemi, "Fragmentation of International Law: Difficulties Arising from the Diversification and Expansion of International Law – Rep. of the Study Group of the Int'l Law Commission" U.N. Doc. A/CN.4/L.682 (2006) 13, paragraph 24.

[44] J Gupta, "Global scientific assessments and environmental resource governance: towards a science–policy interface ladder" in M Ambrus, K Arts (eds), *The Role of "Experts" in International and European Decision-Making Processes* (Cambridge 2014) 148, 150; C Rhodes, "Opportunities and Constraints for Cooperation between International Organizations" (2010) Nordic Envtl LJ 175, 176–7; OECD, *International Regulatory Co-operation: The Role of International Organizations in Fostering Better Rules of Globalization* (OECD Publishing, 2016) 94.

[45] E.g. G Guillaume, President of the International Court of Justice, "Speech to the Sixth Committee of the General Assembly of the United Nations (30 October 2001), <https://www.icj-cij.org/node/102136>; JI Charney, "Is International Law Threatened by Multiple International Tribunals?" The Hague Academy Collected Courses (Brill Nijhoff 1998) 271.

[46] M Honegger, K Sugathapala and A Michaelowa, "Tackling Climate Change: Where Can the Generic Framework Be Located?" (2013) 2 Carbon and Climate Law Review 125, 134; T Kuokkanen and Y Yamineva, *supra* note 3, 165; EJ Larson, "The red dawn of geoengineering: First step toward an effective governance for stratospheric injections" (2016) 14 Duke Law and Technology Review 157–91; J Reynolds, "The International Regulation of Climate Engineering: Lessons from Nuclear Power" (2014) 26 J. of Int. Environmental Law 273–4.

[47] M Koskenniemi, *supra* note 43.

contributions on fragmentation in international law has taken a more positive view, focusing on conceptualising how to deal constructively with fragmentation. This "new and optimistic view" on fragmentation, as Giorgetti and Pollack have noted, "has become the conventional wisdom in the international legal community today".[48] Peters points out that fragmentation can be viewed as an adequate response to the complexities of contemporary life and that fragmentation plays a role in preventing "abuse" by establishing a separation of powers, enabling checks and balances.[49] Young and her contributors demonstrate how the diversification of legal regimes can lead to "productive friction." This term refers to the dynamic interactions between different legal systems that can foster innovation and adaptation within international law. Such interactions may encourage regimes to learn from each other, leading to more effective and context-specific legal solutions.[50]

Following this, a fragmented governance architecture holds the potential to enhance the quality of restrictive SRM governance. As examined in Section II, SRM assessment and deployment presents a complex and multi-dimensional challenge, and would have direct implications for many fields of international cooperation and law. Consequently, the foremost governance challenge lies in encompassing all these diverse impact areas and specialized domains, delineated above. Given that SRM means an unprecedented human intervention into planetary systems and intends to manage the basis of life on Earth, the quality of decision-making should be central to global governance deliberations and arrangements. In this context, fragmentation does not necessarily weaken the unity of international legal systems if applied to governing non-use of SRM. Instead, it has the potential to increase comprehensiveness and coherence of a restrictive, non-use regime.[51]

2. A fragmented architecture: implications for governing SRM use

In governing the use (as opposed to the non-use) of SRM, i.e. developing an SRM deployment regime, the presence of an already existing landscape of institutional obligations poses more significant difficulties. This is particularly true for proposals suggesting a new regime that should have SRM or geoengineering "in mind" in order to increase "coherence" and efficient decision-making.[52] A more in-depth legal examination of how decisions on SRM deployment would relate to existing obligations is still missing in the SRM governance literature.

Creating a new governance system or extending an existing one would not occur in "clinical isolation" from existing frameworks.[53] According to Article 31.3.c VCLT, a new regime designed to govern SRM deployment would have to align with other international treaties and legal obligations as well. This is for two reasons. First, as we elaborate below, this is because the rules for norm collisions do not apply in this setting; and second, because fragmentation of international law is the regular finding, whereas superior norms and regimes that trump others are rare occurrences.

First, the rules for norm collisions are not applicable, since the regimes involved would not regulate the same subject matter. The *lex specialis* rule states that if a "same subject

[48] C Giorgetti and M Pollack, "Cross-Fertilization, Cooperation, and Competition among International Courts and Tribunals" in Giorgetti and Pollack (eds.), Beyond Fragmentation (Cambridge University Press 2022) 3.

[49] A Peters, "The refinement of international law: From fragmentation to regime interaction and politicization" (2017) 15 Int. Journal of Constitutional Law, 671, 680–1.

[50] MA Young, "Introduction: The Productive Friction between Regimes" in MA Young (ed), Regime Interaction in International Law: Facing Fragmentation (Cambridge University Press 2012), 1.

[51] B Simma, Fragmentation in a Positive Light (2004) 25 Mich. J. Int'l L. 845.

[52] E.g. proposed by M Honegger, K Sugathapala and A Michaelowa, *supra* note 46.

[53] The wording "not in clinical isolation" has been framed by the WTO Appellate Body while examining the relation between WTO law and Multilateral Environmental Treaties, see: WTO, United States – Standards for Reformulated and Conventional Gasoline, WT/DS2/AB/R, 20 May 1996, 17.

matter" is regulated by a general and a more specific rule as well, the latter shall prevail. A rule is only more specific in regulating "the same subject matter" if both rules are in some respect similar. Therefore, regimes that have different purpose mandates (e.g. protection of biodiversity, climate protection, human rights, management of SRM) are not, *per se*, regulating the same subject matter. Were that not the case, environmental protection regimes would always be legally subordinated to regimes regulating other "more specific" human activities. But none of these diverse purposes enjoys intrinsic priority over the other.[54]

Instead, the different purpose mandates of existing regimes have to be reconciled bottom up and not top down, and different regimes have to inform each other.[55] In line with this, the International Court of Justice, when examining an extreme circumstance of self-defence in "Legality of the Threat or Use of Nuclear Weapons"[56] did not set aside either the law on the use of force or the humanitarian law. Instead, both had to contribute relevant considerations to the advisory opinion. Our finding that the *lex specialis* rule does not apply between regimes having different purpose mandates does not mean that neither of the two conflicting rules from the different regimes can be applied or take precedence at all; in line with Article 31.3.c VCLT, such a rule should only be applied after thorough consideration of the specific setting. The point is that none of the existing relevant regimes is automatically set aside.

In order to avoid these complexities, states could, in theory, agree on a new regime that should take precedence over existing regimes. States can set aside existing obligations only if they decide to establish a self-contained and superior regime. Such an approach would position a new governance system on top of the hierarchy within the relevant international law. However, this is highly unrealistic and would represent a constitutional leap. This is evidenced by the fact that international law rarely allows for a "trumping" impact of hierarchically superior norms over the norms of other regimes and treaties. Some of the rare examples of such prevailing and quasi-constitutional rules are Article 103 of the UN Charter or the *ius cogens* prohibition of torture.

Turning to international environmental law, even the much-discussed World Environmental Organisation failed to come into existence.[57] Instead, it was agreed that the United Nations Environment Programme (UNEP) shall galvanise actions by other institutions and agencies; it was not given the authority to steer or authoritatively coordinate such actions.[58] It seems unlikely that states will agree on an overarching SRM institution to have the capacity to make decisions on its own or steer other relevant institutions.

Therefore, even if there were a new regime having the mandate to decide on SRM deployment, it would not be in the position to set aside existing regimes and obligations, but Article 31.3.c VCLT and the principle of systemic integration must be applied in any SRM governance regime or architecture.

[54] M Koskenniemi, *supra* note 43, 30, paragraph 117–18.

[55] JH Knox, "The Juidicial Resolution of conflicts between Trade and the Environment" (2004) 28, Harvard Environmental Law Review 1, 66; G Sacerdoti, "WTO Law and the "Fragmentation" of International Law: Specificity, Integration, Conflicts" in ME Janow (ed), WTO: Governance, Dispute Settlement & Developing Countries (NY 2008) 603.

[56] International Court of Justice, Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, 8 July 1996, ICJ Rep. 226.

[57] J Whalley and B Zissimos, "What Could a World Environmental Organization Do?" (2001) 1,1 Global Environmental Politics 29–34.

[58] M Ivanova, "Designing the United Nations environment programme: a story of compromise and confrontation" in International environmental agreements: politics, law and economics Volume 7 (Dordrecht 2007) 348.

IV. Conclusion

We have shown in this article that solar geoengineering is not an ungoverned space. Instead, there is already a significant and noteworthy web of international obligations comprising soft law and hard law that pertains to SRM governance, particularly addressing adverse impacts on atmospheric, marine, biodiversity, geopolitical and human rights, among others. This fragmented institutional landscape already covers most of the impacts that solar geoengineering governance would need to contend with, at least to some degree. Thus, the presumed "gap" in global governance of SRM is not as much of a gap as often alleged in the literature.

Furthermore, our article also shows that the existing institutional complexity is unlikely to be easily reconciled with an enabling regime of SRM governance. Theoretically, there are two options to deal with the institutional complexity in the context of a deployment regime: (i) setting aside existing regimes by creating a superior regime, or (ii) establishing a governance framework for shared decisions on complex questions of actual deployment. Both options would require a constitutional leap in the international system that is unprecedented and that would require global institutional structures that come close to effective supranationalism or even world government,[59] all of which is highly implausible in present-day political and geopolitical contexts.

In contrast, the fragmented landscape and a web of obligations mapped here, relating to a diverse array of adverse impacts associated with potential use of SRM, would support a comprehensive and restrictive governance of SRM. Far from being non-conducive to such restrictive governance, it might have key advantages, providing checks and balances (legally speaking and in terms of norms and principles) against unconsidered, prohibited and ungoverned future deployment. Governing use and deployment would require a very different, very centralised, architecture compared to non-use. Non-use or restrictive governance, in contrast, can emerge and co-exist in multiple governance arenas and venues, including through this existing web of institutions.

[59] Elaborating on further institutional features of a deployment regime and coming to this conclusion are F Biermann, A Gupta, R Kim and F Rabitz "Can solar geoengineering deployment ever be governed?" (2024) A scoping study prepared for the Global Challenges Foundation, on file with authors.

Cite this article: D Ruddigkeit, H Bruggink, and A Gupta, "Solar Geoengineering Governance: A Fragmented Institutional Landscape Covering Multi-Dimensional Impacts". *European Journal of Risk Regulation*. https://doi.org/10.1017/err.2025.10048