Texas A&M Law Review

Volume 11 | Issue 2

5-10-2024

The Evolving International Climate Change Regime: Mitigation, Adaptation, Reflection

Jonathan B. Wiener

Tyler Felgenhauer

Recommended Citation

Jonathan B. Wiener & Tyler Felgenhauer, *The Evolving International Climate Change Regime: Mitigation, Adaptation, Reflection*, 11 Tex. A&M L. Rev. 451 (2024).
Available at: https://doi.org/10.37419/LR.V11.I2.6

THE EVOLVING INTERNATIONAL CLIMATE CHANGE REGIME: MITIGATION, ADAPTATION, REFLECTION

by: Jonathan B. Wiener & Tyler Felgenhauer***

Abstract

The complex international regime for climate change has evolved over the past three decades, from the Framework Convention on Climate Change and the Kyoto Protocol through the Paris Agreement and beyond. We assess this evolution from the 1990s to the 2020s, and its potential future evolution from the 2020s to the 2050s, across three main policy strategies: mitigation, adaptation, and reflection. In its first three decades, the regime has focused predominantly on the mitigation of net emissions and on engaging all major emitting countries in that effort. More recently, as progress on mitigation has been slow and as the impacts of climate change have risen around the world, the regime has begun to address adaptation. The next three decades may see the rise of a third strategy, reflection, if actors (collectively or unilaterally) perceive an urgent need to alleviate peak climate damages through fast-acting but controversial and risky climate interventions known as sunlight reflection methods or solar radiation modification (SRM). Several major international groups have recently issued reports on SRM, yet the international climate change regime has not yet constructed a governance regime for assessment or management of SRM. We recommend and outline comprehensive risk-risk tradeoff analyses of SRM to help avoid harmful countervailing risks. We suggest the development of an adaptive governance regime, starting early and embracing iterative and inclusive learning and updating over time. We urge that among the first key steps should be the development of a transparent international monitoring system for SRM. Such a monitoring system could provide early warning and help deter any unilateral SRM, assess the intended and unintended global and regional impacts of any research or eventual deployment of SRM, foster collective deliberation and reduce the risk of international conflict over SRM, help attribute adverse side effects of SRM to assist those adversely affected, and aid learning to improve the system adaptively over time. Thus, any reflection (of sunlight) should involve ongoing reflection (analysis and revision). Such an SRM monitoring regime is needed before SRM might be deployed, and can be developed at the same time that the focus of current efforts remains on mitigation and adaptation.

DOI: https://doi.org/10.37419/LR.V11.I2.6

* Perkins Professor of Law, and Professor of Environmental Policy and Public Policy, Duke University; Co-Director, Duke Center on Risk; University Fellow, Resources for the Future (RFF). The authors thank Daniel Bodansky, Scott Barrett, Sue Biniaz, Mark Borsuk, Jessica Seddon, Richard Stewart, the journal editors, and participants in conferences at Resources for the Future (RFF), the Society for Social Studies of Science (4S), the Society for Risk Analysis (SRA), TSS (Wyoming), and GETS (Arizona).

** Research Director, Duke Center on Risk, and Senior Research Scientist, Department of Civil and Environmental Engineering, Duke University. The authors acknowledge support for related work from the Carnegie Climate Governance Initiative (C2G) and from NSF grant #1948154 (Wiener and Felgenhauer) and NSF grant #2218779 (Felgenhauer).

TABLE OF CONTENTS

I. INTRODUCTION

In this Article, we review the evolution of the international climate change regime[1] over the past three decades, and we look ahead to the next three decades. In particular, we focus on the policy designs and strategies—the choices among instruments or mechanisms—used in this regime to try to provide climate protection and reduce climate risk.[2] We

1. The "international climate change regime" is of course a complex, plural, and polycentric set of agreements and institutions. *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE 1012 (Otmar Edenhofer et al. eds., 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter13.pdf [https://perma.cc/HSC9-KMAS] (detailing the complex multiple elements of the international climate change regime); Robert O. Keohane & David G. Victor, *The Regime Complex for Climate Change*, 9 PERSPS. ON POL. 7, 7 (2011), https://doi.org/10.1017/S1537592710004068; Martin Jänicke, *The Multi-Level System of Global Climate Governance—the Model and Its Current State*, 27 ENV'T POL'Y & GOVERNANCE 108, 119 (2017), https://doi.org/10.1002/eet.1747. In this Article, we focus on the major international agreements on climate change—the UN Framework Convention on Climate Change (1992), its Kyoto Protocol (1997), the Paris Agreement (2015), and related accords. We also take note of additional related agreements such as the Kigali Amendment (2016) to the Montreal Protocol on Substances that Deplete the Stratospheric Ozone Layer and the International Civil Aviation Organization (ICAO) agreement on greenhouse gas emissions from civil aviation (2016). And we comment on the interplay of these international agreements with other multinational and national institutions.

2. For an overview and analysis of policy instrument choice and its political economy, with attention to climate change policy, see generally Jonathan B. Wiener & Barak D. Richman, *Mechanism Choice*, *in* RESEARCH HANDBOOK ON PUBLIC CHOICE AND PUBLIC LAW (Daniel A. Farber & Anne Joseph O'Connell eds., 2010). In the present

assess the evolution of these policy designs in the international climate change regime from its early days in the 1990s to the present 2020s, and we look ahead at the options for these policy designs in the future toward the 2050s.

Descriptively, we observe an evolution of three types of overall policy strategies: mitigation, adaptation, and reflection. From an initial focus in the 1990s on mitigation (policies to reduce net greenhouse gas emissions to prevent future climate change), which continues, in the 2000s–2020s the regime has added attention to adaptation (policies to reduce the harms of ongoing and future climate change). And now, looking ahead toward 2050, there is increasing discussion of a still inchoate—and controversial—potential additional strategy: reflecting some of the incoming energy from the Sun to cool the Earth, also called "solar geoengineering," "sunlight reflection methods," or "solar radiation modification" (SRM).[3] These three broad strategies—mitigation, adaptation, and reflection—are evolving at the same time and overlapping, without a discrete end to one and start to another, but there is nonetheless an evident elevation in attention to each strategy over time. These strategies might be viewed as substitutes for each other in reducing climate risk, but because they operate at different scales of space and time and pose different tradeoffs among risks, they may be better viewed as potential complements in an evolving and growing portfolio rather than treated as pure substitutes.[4]

After describing these policy instrument choices, we comment on why the regime has evolved as it has, compared with alternative paths it might have followed—an attempt at characterizing the political economy of policy instrument choice in the international climate change arena—with a view to the future.[5] And we offer recommendations for how the future evolution of the regime can incorporate adaptive learning, including by monitoring activities and outcomes

Article, we focus on the international regime—we do not assess all the policy instruments employed in all national and subnational policies.

3. *See* U.S. National Academies of Sciences, Engineering, and Medicine (NASEM), Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance (2021); Stewart M. Patrick, Reflecting Sunlight to Reduce Climate Risk, at vi (2022), https://cdn.cfr.org/sites/default/files/report_pdf/Patrick-CSR93-web.pdf [https://perma.cc/7BQ5-KB56].

4. *See* Joseph E. Aldy & Richard Zeckhauser, *Three Prongs for Prudent Climate Policy*, 87 S. Econ. J. 3, 19 (2019), https://doi.org/10.1002/soej.12433.

5. This is a vexing task, given the ever-changing complex multiplicity of actors, institutions, interests, and issues at the international level and the myriad connections with domestic politics in different countries. *See* Wiener & Richman, *supra* note 2; Jonathan B. Wiener, *Something Borrowed for Something Blue: Legal Transplants and the Evolution of Global Environmental Law*, 27 Ecology L.Q. 1295, 1300 (2001) [hereinafter *Something Borrowed*]; Jonathan B. Wiener, *On the Political Economy of Global Environmental Regulation*, 87 Geo. L.J. 749, 790 (1999).

and updating policy designs for better governance and outcomes over time.[6]

II. Evolution of the International Climate Change Regime

The international climate change regime has evolved from its inception over three decades ago, through a series of agreements from the 1990s to the present in the 2020s, and we conjecture (with uncertainty) that it will continue to evolve over the next three decades toward the 2050s. In this Section, we trace the development of the key policy instruments in the main international climate agreements: the UN Framework Convention on Climate Change (FCCC) (1992),[7] the Kyoto Protocol (1997),[8] the Paris Agreement (2015),[9] and related agreements such as the Kigali Amendment (2016)[10] and the ICAO climate accord (2016).[11] We then assess the possible evolution of future climate policy in the three main policy strategies: mitigation, adaptation, and reflection. Within the category of mitigation, we compare the international agreements on four key elements of policy design: targets/goals, scope, flexibility, and adaptive learning.

A. *Mitigation*

1. The 1990s–2000s

In the 1990s, the initial climate agreements focused on mitigation—policies to reduce net greenhouse gas (GHG) emissions to prevent future climate change. Recognition of the rising atmospheric concentrations of GHGs such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), and their potential adverse climate change impacts, helped lead to the creation of the Intergovernmental Panel on Climate Change (IPCC) and its first assessment report in 1989–90,[12] and to international negotiations on the FCCC from 1990–92.[13] The basic elements

6. On the merits and mechanisms of adaptive regulation, see Lori S. Bennear & Jonathan B. Wiener, *Built to Learn: From Static to Adaptive Environmental Policy*, *in* A Better Planet: Forty Big Ideas for a Sustainable Future (Daniel C. Esty ed., 2019).

7. U.N. Framework Convention on Climate Change, May 9, 1992, 1771 U.N.T.S. 107.

8. Kyoto Protocol to the U.N. Framework Convention on Climate Change, Dec. 11, 1997, 2303 U.N.T.S. 162 [hereinafter Kyoto Protocol].

9. Paris Agreement to the U.N. Framework Convention on Climate Change, Apr. 22, 2016, T.I.A.S. No. 16-1104 [hereinafter Paris Agreement].

10. Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, Oct. 15, 2016, 27 U.N.T.S. 2.

11. *See* Int'l Civ. Aviation Org., On Board a Sustainable Future: 2016 Environmental Report 202 (2016).

12. Intergovernmental Panel on Climate Change, Climate Change: The IPCC 1990 and 1992 Assessments 33 (1992) [hereinafter IPCC 1990].

13. Daniel Bodansky, *The United Nations Climate Change Regime 30 Years on—a Retrospective and Assessment*, 62 Washburn L.J. 1, 10 (2022).

of anthropogenic climate change shaped these treaty negotiations.[14] Emissions of GHGs from around the world contribute to globally mixed atmospheric GHG concentrations and globally shared temperature increases (though with heterogeneous impacts across countries).[15] With globally shared benefits of mitigation, to the extent that reducing GHG emissions is locally costly (through changing modes of energy, transportation, agriculture, land use, or other sources of GHGs, or expanding sinks such as forests), there is an incentive for each actor to wait for others to bear the cost of providing the shared global benefits—to "free ride" on others' mitigation efforts.[16] Moreover, in an increasingly integrated world economy, partial actions to reduce emissions in only some places could be thwarted by shifting sources of emissions to other places—the problem of "carbon leakage."[17] For both of these reasons—overcoming free riding and limiting leakage—international cooperation is needed to engage many countries to participate broadly in collective action to mitigate GHG emissions.[18] In the current international legal system, a treaty is binding on a country only if it consents to join, so engaging both broad participation in treaties and high levels of compliance is a challenge for global collective action, and must involve policy designs that are viewed as net beneficial both globally and locally for each country to join.[19] The FCCC tackled this problem by engaging virtually all countries in two years of negotiations toward agreement on the FCCC, adopted at the Rio Earth Summit (the UN Conference on Environment and Development) in June 1992.[20]

14. *See id.* at 11; *Something Borrowed*, *supra* note 5, at 1366.

15. IPCC 1990, *supra* note 12.

16. *See generally* SCOTT BARRETT, WHY COOPERATE? THE INCENTIVE TO SUPPLY GLOBAL PUBLIC GOODS (2007).

17. *See* Michael Jakob, *Why Carbon Leakage Matters and What Can Be Done Against It*, 4 ONE EARTH 609, 609 (2021), https://doi.org/10.1016/j.oneear.2021.04.010; Rachel Brewster, *Stepping Stone or Stumbling Block: Incrementalism and National Climate Change Legislation*, 28 YALE L. & POL. REV. 245, 246–47 (2010); Jonathan B. Wiener, *Think Globally, Act Globally: The Limits of Local Climate Policies*, 155 U. PA. L. REV. 1961, 1967–79 (2007).

18. *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 1, at 1053; Wiener, *supra* note 17, at 1975–78.

19. *See* Jonathan B. Wiener, *Global Environmental Regulation: Instrument Choice in Legal Context*, 108 YALE L.J. 677, 737, 771–72 (1999); SCOTT BARRETT, ENVIRONMENT AND STATECRAFT: THE STRATEGY OF ENVIRONMENTAL TREATY-MAKING, at xiii, 355 (2003); INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 1, at 1001, 1008, 1010, 1015. Although some forms of international law (e.g., customary international law based on state practice) may arguably be applicable to all countries, attracting participation in treaties requires consent and may thus require additional inducements or "side payments" to some key countries to make their joining the agreement net beneficial for them. *See* Wiener, *supra*, at 679, 755; BARRETT, *supra*, at 357; LLOYD GRUBER, RULING THE WORLD: POWER POLITICS AND THE RISE OF SUPRANATIONAL INSTITUTIONS 24 (2000); GREEN PLANET BLUES: ENVIRONMENTAL POLITICS FROM STOCKHOLM TO JOHANNESBURG 65 (Ken Conca & Geoffrey D. Dabelko eds., 2004).

20. *See generally* U.N. Framework Convention on Climate Change, *supra* note 7.

Within mitigation, there have been at least four fundamental elements of policy instrument design: *targets (or goals), scope, flexibility,* and *adaptive learning*. As to *targets* (or goals)[21]: the FCCC announced in Article 2 its objective to stabilize atmospheric concentrations of GHGs at a level that would prevent dangerous anthropogenic interference with the climate system (though it did not define that level).[22] The FCCC then provided in Article 4 the key instruments to try to attain its objective: commitments by all parties to take measures to mitigate their emissions (Article 4(1)(b)),[23] and commitments by industrialized country parties listed in Annex I to adopt policies and measures to limit emissions and enhance sinks by the year 2000 (Article 4(2)(a))[24] and to communicate periodically on their progress "with the aim of returning individually or jointly to their 1990 levels" (Article 4(2)(b)).[25] The distinction between Annex I countries (with quasi-quantitative emissions mitigation targets) and non-Annex I countries (with only qualitative emissions mitigation commitments) reflected the principle of "common but differentiated responsibilities and respective capabilities" (CBDR) advanced in Article 3(1) of the treaty.[26]

A second key element of policy instrument design in the FCCC was the *scope* of these policies. The FCCC did not cover only energy sector CO2 emissions; rather, in Article 3(3), it called for "policies and measures . . . [to] be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors,"[27] and in Articles 4(1)(b) and 4(2), its targets covered all sources and sinks of all GHGs not controlled by the Montreal Protocol.[28] Thus, the FCCC covered CO2, CH4, and N2O as well as several other GHGs; covered sources in all sectors; and sinks such as forests as well. This had been a serious point of contention in the negotiations, with the European Union (EU) initially favoring a limited focus on energy-related CO2 emissions only, while the United States advanced the comprehensive approach to net emissions of all GHGs from all sources and sinks.[29] The United States argued that this more comprehensive scope would be both environmentally superior, by preventing cross-gas shifts

21. In this context we use the term "targets" (or "goals") broadly, to refer to the extent or degree of mitigation sought to be attained under the regime, including through various forms such as quantitative limits on emissions, on concentrations, or on temperatures; qualitative goals; and commitments to adopt mitigation policies and measures. As we discuss, the form of such targets or goals can significantly influence their effectiveness, cost, and other characteristics. *See* Bodansky, *supra* note 13, at 10; Wiener & Richman, *supra* note 2.

22. U.N. Framework Convention on Climate Change, *supra* note 7, at 169.

23. *Id.* at 170.

24. *Id*. at 171.

25. *Id.* at 172.

26. Intergovernmental Panel on Climate Change, *supra* note 1, at 1008. *See* Bodansky, *supra* note 13, at 10.

27. U.N. Framework Convention on Climate Change, *supra* note 7, at 169–70.

28. *Id.* at 170.

29. *See Something Borrowed, supra* note 5, at 1309–14.

(e.g., a shift from coal to natural gas that reduces CO2 emissions but increases CH4 emissions, or a shift from fossil fuels to biofuels that reduces CO2 but increases N2O from agricultural fertilizers and also deforests carbon sinks), and economically superior, by enabling a wider range of opportunities for cost-effective mitigation.[30]

A third important element of the FCCC policy design was the *flexibility* of its mitigation policies. The FCCC negotiations debated whether to employ emissions trading—a policy instrument that had recently been introduced in the United States (to reduce lead in gasoline in the 1980s and to reduce sulfur dioxide (SO2) emissions to mitigate acid rain in the 1990s).[31] An emissions trading system (ETS) (in the climate context, also called a carbon market) offers the opportunity to achieve aggregate emissions reductions at lower cost, by enabling flexibility across sources in the location of emissions reductions.[32] Where different emissions sources have varying marginal costs of abatement, such flexibility in ETS markets enables more cost-effective (lower marginal cost) emissions reduction opportunities to be enlisted. The FCCC ultimately included language in Article 3(3) allowing mitigation efforts to be "carried out cooperatively by interested Parties," and in Article 4(2)(a) authorizing Parties to "implement [their] policies and measures jointly with other Parties," known as "joint implementation" (JI), which was essentially an informal ETS approach for collaborative mitigation efforts across countries.[33] The FCCC did not adopt a full formal ETS (or "cap and trade" system) for several reasons, including opposition to formal GHG emissions trading in the EU in the early 1990s (which did not yet have experience with ETS approaches), and opposition to

30. *See id.* at 1309–14, 1320–27. For the early formulation and advocacy of this "comprehensive approach," on both environmental and economic criteria, see Richard B. Stewart & Jonathan B. Wiener, *The Comprehensive Approach to Global Climate Policy: Issues of Design and Practicality*, 9 ARIZ. J. INT'L & COMPAR. L. 83, 86 (1992); Jonathan B. Wiener, *Protecting the Global Environment*, *in* RISK VS. RISK: TRADEOFFS IN PROTECTING HEALTH AND THE ENVIRONMENT 193, 222 (John D. Graham & Jonathan B. Wiener eds., 1995). For the economic cost-effectiveness advantages of a multi-gas approach, see John Reilly et al., *Multi-Gas Assessment of the Kyoto Protocol*, 401 NATURE 549, 549 (1999). The environmental advantages of a comprehensive multi-gas approach in preventing cross-gas shifts, such as from CO2 to CH4 emissions, have been analyzed further in recent years (especially after the advent of hydraulic fracturing, or fracking, increased the supply of natural gas). *See* Deborah Gordon et al., *Evaluating Net Life-cycle Greenhouse Gas Emissions Intensities from Gas and Coal at Varying Methane Leakage Rates*, ENV'T. RSCH. LETTERS, July 17, 2023, at 1, https://doi.org/10.1088/1748-9326/ace3d-biopscience.iop.org/article/10.1088/1748-9326/ace3db.

31. *See Something Borrowed*, *supra* note 5, at 1311–15.

32. *See* WORLD BANK, EMISSIONS TRADING IN PRACTICE: A HANDBOOK ON DESIGN AND IMPLEMENTATION (2016), https://openknowledge.worldbank.org/entities/publication/c0e89d6b-e90a-592b-a4c7-1c5a20d82f2c [https://perma.cc/VN4B-Z5TN]; INTERNATIONAL ENERGY AGENCY, IMPLEMENTING EFFECTIVE EMISSIONS TRADING SYSTEMS: LESSONS FROM INTERNATIONAL EXPERIENCES (2020), https://www.iea.org/reports/implementing-effective-emissions-trading-systems [https://perma.cc/9UAT-XAB6].

33. U.N. Framework Convention on Climate Change, *supra* note 7, at 170–71; *see Something Borrowed*, *supra* note 5, at 1309–12; Bodansky, *supra* note 13, at 4.

a formal quantitative cap on aggregate emissions in part of the U.S. government (where some U.S. officials favored cap and trade, as the United States was doing for SO2, while other U.S. officials opposed caps for GHGs).[34]

A fourth key element of the policy instrument design in the FCCC was its process for *adaptive learning*. This characteristic of policy decisions and legal rules can be seen on a spectrum, from completely static (a one-time decision that is fixed in perpetuity) to completely adaptive (a sequence of multiple decisions that adjust instantaneously to each new iota of information), with real policies typically falling somewhere along this spectrum.[35] More adaptive sequential decision processes involve some mechanisms for learning, such as monitoring, analyzing, reviewing, and potentially revising or updating the prior policy.[36] In some cases, adaptive updating is unplanned, in the sense of responding to a surprise such as a crisis or a discovery; in others, adaptive updating is planned, with a process designed to conduct monitoring, analysis, review, and revision over time.[37] Planned adaptive regulation, in turn, can be discretionary (such as a judgment reached by an expert committee and adopted by a regulator) or automated (such as a policy designed ex ante to adjust if a trigger value of an indicator variable is reached—for example, issuing additional tradable allowances from a reserve if the allowance market price exceeds a trigger level).[38]

The FCCC was conceived as an adaptive process. It was labeled a "framework convention" that would later be followed by further protocols.[39] It set initial target commitments for the year 2000, leaving subsequent commitment periods to be set by these follow-on protocols.[40] It launched a series of annual Conferences of the Parties (COPs) that revised the targets and policy instrument designs over time.[41] It called for regular reporting on emissions and progress in policies and measures.[42] Article 4(1)(f) also called for parties to conduct impact assessments of

34. *See Something Borrowed*, *supra* note 5, at 1311–27; Wiener & Richman, *supra* note 2.

35. *See* Bennear & Wiener, *supra* note 6, at 353–55.

36. *See id.* at 355–57.

37. *Id.* at 355–66; Lawrence E. McCray et al., *Planned Adaptation in Risk Regulation: An Initial Survey of US Environmental, Health, and Safety Regulation*, 77 Tech. Forecasting & Soc. Change 951, 951 (2009), https://doi.org/10.1016/j.techfore.2009.12.001; Justin R. Pidot, *Governance and Uncertainty*, 37 Cardozo L. Rev. 113, 113 (2015).

38. *See* Bennear & Wiener, *supra* note 6, at 357–58.

39. *See generally* Bodansky, *supra* note 13, at 2–3.

40. *Id.* at 3.

41. *See id.*; *see also* U.N. Framework Convention on Climate Change, *supra* note 7, at 176.

42. U.N. Framework Convention on Climate Change, *supra* note 7, at 176, 180–81.

their climate protection actions.[43] The 1995 Berlin meeting agreed to go further than the FCCC, leading to the 1997 Kyoto Protocol.[44]

The Kyoto Protocol amplified each of the four policy designs discussed above. It adopted quantitative emissions reduction *targets* for Annex I countries (listed in Annex B), enumerated as percentage changes from base year emissions to be achieved through the first commitment period, "with a view to reducing their overall emissions [of such gases] by at least 5% below 1990 levels in the 'commitment period' 2008-2012" (Article 3(1)).[45] It covered a comprehensive *scope* of GHGs (six sets of gases, including CO2, CH4, N2O, PFCs (perfluorocarbons), and others), and both sources and sinks. It authorized *flexibility* mechanisms including cooperative JI among industrialized countries[46] (Articles 3(1) and 4); more formal "emissions trading" among industrialized countries with quantitative emissions limits[47] (Articles 6 and 17); and a new "Clean Development Mechanism" (CDM) (Article 12) to enable non-Annex I developing countries to sell offset credits to actors in Annex I countries.[48] And it called for an *adaptive* process of regular reporting and review of national progress (Articles 7 and 8), periodic reviews of the overall Protocol (Article 9), and consideration by the COPs of potential further commitment periods (Articles 3(9) and 21(7)).[49] But because the quantitative mitigation commitment targets (or caps) in the Kyoto Protocol applied only to Annex I countries, raising concerns about competitiveness and about GHG leakage, the U.S. Senate voted unanimously 95-0 to adopt the Byrd-Hagel Resolution stating its determination not to ratify what became the Kyoto Protocol

43. *Id*. at 170–71.

44. UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, A GUIDE TO THE CLIMATE CHANGE CONVENTION PROCESS (2002), https://unfccc.int/resource/process/guideprocess-p.pdf [https://perma.cc/T4ZL-7QUC].

45. Kyoto Protocol, *supra* note 8, art. 3(1).

46. *Id.* arts. 3(1), 4.

47. *Id.* arts. 6, 17.

48. Unlike formal cap and trade ETS approaches, where allowance sellers are subject to caps and government monitoring, the CDM and other offset credit markets, in which credit sellers are not subject to caps, may help mobilize financial flows for emissions reductions to uncapped jurisdictions—such as developing countries seeking to conserve forests (as under the Reducing Emissions from Deforestation and Degradation, or REDD+ program)—but may also raise concerns that these uncapped offset credits overstate the real emissions reductions they represent, such as by exaggerating the emissions that would have occurred in the baseline scenario without the offset credit arrangement. *See* RICHARD B. STEWART & JONATHAN B. WIENER, RECONSTRUCTING CLIMATE POLICY: BEYOND KYOTO 74 (2003) (advocating for an ETS but raising concerns about the CDM); Alejandro Guizar-Coutiño et al., *A Global Evaluation of the Effectiveness of Voluntary REDD+ Projects at Reducing Deforestation and Degradation in the Moist Tropics*, CONSERVATION BIOLOGY, June 17, 2022, at 1, https://doi.org/10.1111/cobi.13970 (finding significant reductions in deforestation in a sample of REDD+ projects); Thales A.P. West et al., *Action Needed to Make Carbon Offsets from Forest Conservation Work for Climate Change Mitigation*, 381 SCIENCE 873, 873 (2023) (finding carbon offset claims overstated in a sample of REDD+ projects).

49. Kyoto Protocol, *supra* note 8, arts. 3(9), 7, 9, 21(7).

in 1997 unless it included meaningful commitments by major developing countries.[50] Vice President AI Gore signed the Kyoto Protocol, but President Bill Clinton never submitted it to the Senate for advice and consent to ratification, and about three years later President George W. Bush withdrew the U.S. signature.[51] Thus the United States remained a party to the FCCC but did not join the Kyoto Protocol.

Meanwhile, as to *flexibility*, the EU changed its stance on emissions trading from opposition to embrace. Starting in the early 2000s, the EU launched its own ETS.[52] Several factors contributed to the EU reversal to adopt the ETS, including the ambition for deeper emissions reductions, the high overall cost with significant variation in marginal cost of emissions reductions across Europe, the learning experience of the successful U.S. SO2 acid rain trading program, and the internal politics of gaining agreement among the EU member states.[53] Soon, the northeastern states of the U.S. adopted the Regional Greenhouse Gas Initiative (RGGI) starting their ETS in 2009, and California launched its ETS in 2013.[54] Later, China tested a set of regional pilot emissions trading systems and built on them to launch its national ETS by 2019.[55] ETSs were also adopted in several other countries, and some countries adopted carbon taxes.[56] Overall, emissions trading became a leading policy instrument for addressing GHG emissions mitigation around the world.[57]

50. S. Res. 98, 105th Cong. (1997); *see generally* Susan Biniaz, *What Happened to Byrd-Hagel? Its Curious Absence from Evaluations of the Paris Agreement*, SABIN CTR. FOR CLIMATE CHANGE L. (2018), https://scholarship.law.columbia.edu/sabin_climate_change/87.

51. *See* A.C. Thompson, *Timeline: The Science and Politics of Global Warming*, PBS (Apr. 24, 2011), https://www.pbs.org/wgbh/pages/frontline/hotpolitics/etc/cron.html [https://perma.cc/HW65-48XP]; *The Last Time a US President Dumped a Global Climate Deal,* ABC News (June 1, 2017), https://abcnews.go.com/Politics/time-us-president-dumped-global-climate-deal/story?id=47771005 [https://perma.cc/JAE4-FECG].

52. *See generally* A. DENNY ELLERMAN ET AL., PRICING CARBON: THE EUROPEAN UNION EMISSIONS TRADING SCHEME (2010); *Development of EU ETS (2005–2020)*, EUR. COMM'N, https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/development-eu-ets-2005-2020_en [https://perma.cc/JLT2-6S2F].

53. *See* Wiener & Richman, *supra* note 2, at 363.

54. *See* Lara Dahan et al., *Regional Greenhouse Gas Initiative (RGGI): An Emissions Trading Case Study*, ENV'T DEF. FUND (Apr. 2015), https://www.edf.org/sites/default/files/rggi-ets-case-study-may2015.pdf [https://perma.cc/LZ2N-VLSA]; INT'L CARBON ACTION PARTNERSHIP, USA - CALIFORNIA CAP-AND-TRADE PROGRAM (2022), https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-45.pdf [https://perma.cc/EU4J-NCCA].

55. *See* Jingbo Cui et al., *The Effectiveness of China's Regional Carbon Market Pilots in Reducing Firm Emissions*, PNAS, Dec. 20, 2021, at 1, https://doi.org/10.1073/pnas.2109912118.

56. *See generally* INT'L CARBON ACTION PARTNERSHIP, EMISSIONS TRADING WORLDWIDE: STATUS REPORT 2023 (2023), https://icapcarbonaction.com/system/files/document/ICAP%20Emissions%20Trading%20Worldwide%202023%20Status%20Report_0.pdf [https://perma.cc/HWE4-KCRF] [hereinafter EMISSIONS TRADING WORLDWIDE 2023].

57. For data on these several ETSs, see *id.*

2. The 2010s–2020s

Rising concern about climate change impacts, and the absence in the Kyoto Protocol of quantitative mitigation commitments by China and other major developing countries with rapidly rising emissions (which had contributed to the U.S. Senate's 95-0 vote against joining Kyoto), led to talks on ways to engage all major emitting countries in broader climate action. Stewart and Wiener, who had earlier proposed the comprehensive approach and emissions trading policies for the FCCC,[58] then proposed that the United States and China should engage in bilateral cooperation on a parallel regime, running alongside the Kyoto regime, so that the two could be compared in real-time outcomes studies, eventually to merge the regimes into a new global accord based on this adaptive learning process.[59] The United States and other governments launched the Major Economies Forum (MEF) to better engage China and prepare the way toward a new post-Kyoto regime with more global participation.[60] In 2009, the United States and China began a series of bilateral talks and announcements that helped catalyze action at the subsequent COPs in Copenhagen, Cancun, and Paris.[61] These steps indicated that the concept of CBDR in the climate treaties would involve "differentiated" responsibility (i.e., different targets for different countries), but would still need to embody "common" or shared responsibility among all major emitters if global GHG levels were to be effectively constrained.

The crucial challenge of engaging China in order to mitigate global GHG emissions is illustrated in the reordering of U.S. and Chinese rankings in annual emissions. Back in 1992, when Annex I was adopted in the FCCC, and even in 1997, when the Kyoto Protocol set quantitative mitigation targets for Annex I countries, the United States emitted almost twice as much CO2 as did China.[62] In 1997, the U.S. government was forecasting that China and other developing countries would surpass the United States and Annex I countries in annual CO2 emissions

---

58. *See Something Borrowed*, *supra* note 5, at 1295; Stewart & Wiener, *supra* note 30, at 86.

59. *See* Stewart & Wiener, *supra* note 48, at 13.

60. *See* White House Press Release, Off. of the Press Sec'y, President Obama Announces Launch of the Major Economies Forum on Energy and Climate (Mar. 28, 2009), https://obamawhitehouse.archives.gov/realitycheck/the-press-office/president-obama-announces-launch-major-economies-forum-energy-and-climate [https://perma.cc/N6XN-5C92]. The MEF continues to meet. *See White House, Chair's Summary of the Major Economies Forum on Energy and Climate*, White House (Apr. 21, 2023), https://www.whitehouse.gov/briefing-room/statements-releases/2023/04/21/chairs-summary-of-the-major-economies-forum-on-energy-and-climate-held-by-president-joe-biden-2/ [https://perma.cc/EQN3-ETYG].

61. *See* Press Release, Off. of the Press Sec'y, U.S.-China Joint Statement (Nov. 17, 2009), https://obamawhitehouse.archives.gov/realitycheck/the-press-office/us-china-joint-statement [https://perma.cc/N6XN-5C92].

62. *See Annual CO2 Emissions*, Our World in Data, https://ourworldindata.org/grapher/annual-co2-emissions-per-country [https://perma.cc/XM6U-LGJW].

by 2030.[63] But China actually surpassed the United States much sooner, in about 2006.[64] Since then, U.S. emissions have declined while China's emissions have risen sharply; by 2020, the positions were reversed, with China emitting more than twice as much CO2 as the United States.[65] Meanwhile, China's regional and national ETSs and its investments in renewable energy are beginning to bend down its trajectory of rising emissions toward its announced goal of peaking emissions (at some level to be seen) by around 2030.[66]

Talks began toward a second commitment period of the Kyoto Protocol, extending to about 2020, but some key countries (such as Japan and Canada) which had joined the first Kyoto commitments hesitated to join a second round.[67] Seeking broader of participation, and building on the MEF, the Copenhagen meeting, the EU ETS and the U.S.–China bilaterals, then countries negotiated the Paris Agreement adopted at COP21 in 2015.[68] As a global *goal*, the Paris Agreement called on parties collectively to keep the increase in global average surface temperature (above a preindustrial level) to "well below 2°C," and pursue efforts toward 1.5°C (Article 2(1)), in order to avoid significantly higher temperature increases by 2100 and beyond.[69] (Still, observations indicate that by the mid-2020s the planet may already be surpassing the 1.5° increase.[70]) To broaden participation, while adhering to the principle of CBDR (Articles 2(2) and 4(3)), the Paris Agreement sought to overcome the Annex I/Non-Annex I divide by engaging all countries to take action, by allowing each country to set its own Nationally Determined Contribution (NDC) (Articles 3 and 4).[71] These NDCs are pledges of national *targets* or actions, set by each country, which are then to be implemented through domestic institutions.[72] They broaden global participation and thus boost global ambition to reduce GHG emissions; but they may still enable countries to pledge less, or

63. *See* President's Council of Economic Advisers, Economic Report of the President 171 (1998) (chart 5-6), https://www.govinfo.gov/content/pkg/ERP-1998/pdf/ERP-1998.pdf [https://perma.cc/25PR-GHS6].

64. *Annual CO2 Emissions*, *supra* note 62.

65. *Id.*

66. *See* Cui et al., *supra* note 55, at 1.

67. *See* Alex Morales & Stuart Biggs, *Japan Says 'No' to Kyoto Extension, Wants World Treaty*, Bloomberg (Dec. 1, 2010), https://www.bloomberg.com/news/articles/2010-11-30/world-shouldn-t-wait-for-u-s-resolution-on-climate-agreement-japan-says [https://perma.cc/6CL5-8QC4]; *Canada Pulls Out of Kyoto Protocol*, Guardian (Dec. 12, 2011), https://www.theguardian.com/environment/2011/dec/13/canada-pulls-out-kyoto-protocol [https://perma.cc/ALC4-Y3P8].

68. *See* Paris Agreement, *supra* note 9.

69. *Id.* art. 2, para. 1(a).

70. *See* Intergovernmental Panel on Climate Change, Climate Change 2023: Synthesis Report 12 (H. Lee & J. Romero eds., 2023); UN Env't Programme, Emissions Gap Report 2022: The Closing Window 1 (2022) [hereinafter Emissions Gap Report 2022].

71. Paris Agreement, *supra* note 9, arts. 3–4.

72. *Id.* art. 4, para. 2.

pledge more but achieve less, in a version of free riding. Estimates of the combined global effect of current NDCs indicate that, if achieved, they would reduce the increase in global average surface temperature from about 3°C (or higher) by 2100, down closer to 2°C, especially if additional long-term pledges are achieved, but more ambitious NDCs and long-term targets (with full implementation) would be needed to keep the planet below 2° and closer to the 1.5° level.[73] In addition, at the 2021 Glasgow COP26, parties to the Paris Agreement launched a Global Methane Pledge (signed by 149 countries and the European Union, aiming to reduce global anthropogenic methane emissions by 30% in 2030 compared to 2020 levels) and a Global Deforestation Pledge.[74]

As to the *scope* of these mitigation measures, the Paris Agreement and NDCs cover a comprehensive set of multiple GHGs, in all sectors, and sinks as well as sources. Regarding *flexibility*, the Paris Agreement in Article 6 authorizes international emissions trading markets via "internationally transferred mitigation outcomes towards nationally determined contributions" (Article 6(2)) and a "mechanism to contribute to the mitigation of greenhouse gas emissions" via host party emissions reductions that are used by another party (Article 6(4)) to be defined through rules and procedures adopted at subsequent COPs (Article 6(7)).[75] The Paris Agreement encourages parties to adjust their NDCs *adaptively* over time to attain "progression beyond" past NDCs (Article 4(3)), "with a view to enhancing its level of ambition" (Article 4(11)).[76] It calls for a transparency framework of national communications and reports, with technical expert reviews, to track parties' emissions from sources and removals by sinks, their progress toward achieving their NDCs, their adaptation actions, and their efforts toward international financial support (Article 13).[77] And the Paris Agreement sets a schedule of "stocktake[s]" (Article 14) every five years to assess policies and progress.[78]

73. Climate Analytics, Climate Action Tracker: Warming Projections Global Update 7 (2022) [https://perma.cc/BS3W-52NW]; Bodansky, *supra* note 13, at 22–24 (giving the international climate regime high marks for mobilizing normative commitments but lower marks on actual outcomes in reducing global emissions).

74. *See* Climate & Clean Air Coal., Global Methane Pledge (2021); Christopher S. Malley et al., *A Roadmap to Achieve the Global Methane Pledge*, Envt'l Rsch: Climate, Feb. 6, 2023, at 1, 2, https://doi.org/10.1088/2752-5295/acb4b4. COP26 in 2021 also declared a Global Deforestation Pledge. *See* Alexandra Sharp, *Global Deforestation Accelerated in 2022*, Foreign Pol'y (June 27, 2023, 7:00 PM), https://foreignpolicy.com/2023/06/27/climate-change-deforestation-carbon-emissions-brazil-congo/ [https://perma.cc/S7FD-ZZUH]. COP28 in late 2023 announced a goal to transition away from fossil fuels.

75. *See* Emissions Trading Worldwide 2023, *supra* note 56; Paris Agreement, *supra* note 9, art. 6, paras. 2, 4, 7; *see also supra* text accompanying note 48.

76. Paris Agreement, *supra* note 9, art. 4, paras. 3, 11.

77. *Id.* art. 4, para. 13.

78. *Id.* art. 14. The first global stocktake was finalized for COP28 in 2023. *See* Brad Plumer, *Climate Report Card Says Countries Are Trying, But Progress Is Still Slow*, N.Y. Times (Sept. 13, 2023), https://www.nytimes.com/2023/09/08/climate/

In addition to the agreements under the FCCC (including Kyoto and Paris), the regime complex also includes other agreements on mitigation of GHG emissions.[79] Notably, the Kigali Amendment (2016) to the Montreal Protocol phases down the use of hydrofluorocarbons (HFCs), which are substitutes for earlier generations of ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).[80] The HFCs are not ozone-depleting, but are potent GHGs, so phasing them down is estimated to reduce projected global average surface warming by about 0.25°-0.40° C by 2100 (a significant amount in the context of the Paris Agreement goals to limit global temperature increases to 2.0° or even 1.5°).[81] Meanwhile, the International Civil Aviation Organization (ICAO) agreed on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (2016), which seeks to limit commercial aviation GHG emissions through an offset trading system.[82]

3. Toward the 2030s–2050s

With these past efforts and trends in mind, we can offer some conjectures about mitigation in the coming three decades. Mitigation—reducing net emissions to forestall climate change—has been the focus of the international climate regime so far. Yet progress on mitigation has been slow. The shared global benefits (reduced climate damages) but

---

paris-agreement-stocktake.html; Press Release, Climate Council, Implementation Must Accelerate to Increase Ambition Across All Fronts, Taking an All-of-society Approach to Make Progress Towards the Paris Agreement Goals and Respond to the Climate Crisis, Finds Technical Report on First Global Stocktake, United Nations (Sept. 8, 2023), https://unfccc.int/news/implementation-must-accelerate-to-increase-ambition-across-all-fronts-taking-an-all-of-society [https://perma.cc/B8ER-PHMC] [hereinafter *Climate Council*]. *See generally* UN Climate Change Conference, *Technical Dialogue of the First Global Stocktake Synthesis Report by the Co-Facilitators on the Technical Dialogue*, FCCC/SB/2023/9 (Sept. 8, 2023) (describing stocktake); Jama Srouji & Deirdre Cogan, *What Is the Global Stocktake and How Can It Accelerate Climate Action*, World Res. Inst. (Sept. 8, 2023), https://www.wri.org/insights/explaining-global-stocktake-paris-agreement [https://perma.cc/SA33-RQ76] (explaining the stocktake process).

79. In addition to international treaties, other dimensions of international legal regimes have also been brought to bear on climate change, such as litigation under international human rights law. *See* John H. Knox, *Climate Change and Human Rights Law*, 50 Va. J. Int'l L. 163, 168–69 (2009); Annalisa Savaresi & Joana Setzer, *Rights-Based Litigation in the Climate Emergency: Mapping the Landscape and New Knowledge Frontiers*, 13 J. Hum. Rts. & Env't 7, 8 (2022).

80. The United States negotiated and signed it in 2016; it entered into force in 2019. The U.S. Senate ratified the Kigali Amendment on September 21, 2022. *See* Press Release, Off. of the Spokesperson, U.S. Ratification of the Kigali Amendment (Sept. 21, 2022), https://www.state.gov/u-s-ratification-of-the-kigali-amendment/ [https://perma.cc/3M9S-7TDM].

81. *See* Guus J.M. Velders et al., *Projections of Hydrofluorocarbon (HFC) Emissions and the Resulting Global Warming Based on Recent Trends in Observed Abundances and Current Policies*, 22 Atmospheric Chemistry & Physics 6087, 6087 (2022), https://doi.org/10.5194/acp-22-6087-2022.

82. *See Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*, Int'l Civ. Aviation Org., https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx [https://perma.cc/8G8J-858B].

perceived local costs of mitigation (such as the perceived costs to producers, consumers, and workers of transitioning from coal to natural gas to renewables) create incentives for political leaders to go slowly on mitigation and free ride on others' abatement.[83] Opposition to mitigation by interest groups representing industry incumbents raises obstacles to decarbonizing national economies. Still, some national governments have exhibited greater ambition on mitigation. Anticipated future emissions targets, cost-effective regulatory instruments with broad *scope* and ETS *flexibility*, coupled with the declining relative prices and increasing market shares of renewable energy sources (wind and solar), as well as forest conservation efforts and other factors, have helped mobilize private sector investment and reduce net emissions in several countries.[84] But over the last three decades, growing emissions in non-Annex I countries, such as China and India, on top of the large cumulative emissions of Annex I countries (whose annual emissions are now declining), have contributed to the continuing rise in global atmospheric concentrations of GHGs.[85] Overall, collective mitigation efforts through NDCs under the Paris Agreement are partially, but not fully, reducing the projected global average surface temperature toward the 2.0° and 1.5° C goals of the Paris Agreement.[86]

To be successful, future international mitigation efforts should attempt to increase the ambition (stringency) of emissions reduction *target* commitments, in all countries including major emitting developing countries (with appropriate financial and technical assistance),[87] while continuing to employ the comprehensive *scope* and *flexibility* mechanisms to ensure environmental effectiveness and economic cost savings. In addition to ETSs with scheduled tightening (increasing ambition) of quantity-based emissions caps, some countries are employing price-based carbon taxes, both domestically and to address imports from less-regulated jurisdictions (possibly raising trade disputes).[88] Further, international agreements and national policies may attempt to increase the use and reduce the cost of carbon dioxide removal (CDR) methods, such as expanding forest sinks, changing agricultural methods,

83. *See* BARRETT, *supra* note 16.

84. *See Annual CO2 Emissions*, *supra* note 62.

85. *See* ENERDATA, GHG EMISSIONS IN DEVELOPING COUNTRIES—ISSUES AND PERSPECTIVES FOR COP-26 2, 9 (2021), https://d1owejb4br3l12.cloudfront.net/publications/executive-briefing/ghg-emissions-trends-developing-countries-enerdata-brief.pdf [https://perma.cc/P5QU-6B6W].

86. See EMISSIONS GAP REPORT 2022, *supra* note 70; EMISSIONS TRADING WORLDWIDE 2023, *supra* note 56.

87. *See* Rachel Glennerster & Seema Jayachandran, *Think Globally, Act Globally: Opportunities to Mitigate Greenhouse Gas Emissions in Low- and Middle-Income Countries*, 37 J. ECON. PERSPECTIVES 111–36 (2023), https://doi.org/10.1257/jep.37.3.111. This Article uses the same title as Wiener, *supra* note 17 (also urging global action to address the shared global challenge of climate change).

88. *See* WORLD BANK, GROUP STATE AND TRENDS OF CARBON PRICING 16–32 (2023) (surveying carbon taxes and ETSs worldwide).

and improving related nature-based approaches; carbon capture and storage (CCS) systems that remove and sequester GHG effluent from emissions sources such as electric power plants; and direct air capture (DAC) of CO2 or other GHGs from the atmosphere.[89] One question will be how these CDR methods will be credited in the accounting systems for ETSs and carbon taxes.

The series of annual COPs, adjustment of NDCs, and five-year stocktakes under the Paris Agreement (as well as IPCC reports, other international assessments, national government studies, and academic research) offer a set of mechanisms for *adaptive learning*—if they are combined with good systems of monitoring, analysis, review, and updating.[90] Ideally the five-year stocktakes should assess not only the intended reductions in emissions of GHGs to meet targets, but also potential unintended side effects (risk-risk tradeoffs, such as co-benefits and countervailing risks from new energy technologies and land use methods, and effects on underrepresented communities), and they should compare the policy designs employed by countries across multiple NDCs in order to assess which policy designs are most successful and could be borrowed by others.[91] Adaptive regulation offers the benefits of learning to improve policies over time, but it can also mean costs from delay and policy instability.[92] Conversely, a one-time policy solution that is "sticky" against revision[93] may face political opposition, and may yield errors (such as unintended countervailing risks) as the world changes over time and as new knowledge indicates that regulation of a complex problem requires a more complex or revised policy design.[94] Sticky regulation may help shield climate policy against interest group pressures to relax rules, but it may also raise the ex ante anticipated costs of adopting such rules and thus may deter adoption (especially at the international level where countries must consent to join). Given the structure of international regimes and treaties by consent, adaptive learning may be the best path forward despite its downsides—clearly better than an impasse. The FCCC COPs, Paris NDCs

89. *See generally* Working Group III: Mitigation of Climate Change, Chapter 7 Agriculture, Forestry, and Other Land Uses, *in* IPCC Sixth Assessment Report (2022); *CDR Fact Sheet*, Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar6/wg3/downloads/outreach/IPCC_AR6_WGIII_Factsheet_CDR.pdf [https://perma.cc/CG2N-JBYA].

90. *See* Bennear & Wiener, *supra* note 6, at 354–59; Jonathan B. Wiener, *Towards an Effective System of Monitoring, Reporting and Verification*, *in* Towards a Workable and Effective Climate Regime (Scott Barrett et al. eds., 2015), https://cepr.org/publications/books-and-reports/towards-workable-and-effective-climate-regime [https://perma.cc/B43Z-XGHX].

91. *See* Wiener, *supra* note 90, at 193.

92. *See* Bennear & Wiener, *supra* note 6, at 354–55.

93. *See* Richard J. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future*, 94 Cornell L. Rev. 1153, 1193 (2009); Aaron L. Nielsen, *Sticky Regulations*, 85 U. Chi. L. Rev. 85, 85 (2018).

94. *See* Bennear & Wiener, *supra* note 6, at 353.

and stocktakes, and regular IPCC reports, as well as national government policy processes and academic research, offer potential paths for adaptive learning and sequential updating. To succeed, they need good information—monitoring, analysis, review—to provide the basis for actual learning and policy improvement.

B. *Adaptation*

With slow progress on mitigation and increasing impacts from climate change (such as wildfires, extreme storms, drought, and sea level rise), adaptation is increasingly needed to reduce these damages. Adaptation continues to be a secondary priority in the international climate regime despite receiving continued and growing attention. In part this reflects the differing incentive posture of adaptation from mitigation: If the benefits of adaptation actions mainly accrue locally, within a country or region, then these local governments may have strong incentives to invest in adaptation, but other countries may have less incentive to assist with adaptation (than with mitigation that yields shared benefits). Adaptation may be seen as a private or club good whereas mitigation may be seen as a public good. And the rising attention to adaptation in part reflects the growing voice of developing countries in international arenas, because some developing countries (such as small island states and countries vulnerable to drought or storms) are among the most vulnerable to climate damages. But just as mitigation can yield countervailing risks (e.g., the environmental risks of switching from fossil fuels to nuclear energy, or the cross-gas shifts noted above from switching from coal to gas and thus from CO2 to CH4, or biofuels that reduce tailpipe CO2 emissions but increase N2O and deforestation), so can adaptation. Well-designed adaptation can build resilience to bounce back from future impacts, but "maladaptation" can harm communities and ecosystems (such as by building sea walls that interfere with water and nutrient flows and ecosystem interconnections).[95]

The FCCC focused more on mitigation of GHG emissions than on adaptation. It did refer to adaptation in its objective (Article 2) and principles (Article 3).[96] In its commitments (Article 4), the FCCC called on all parties to undertake "measures to facilitate adequate adaptation to climate change" (Article 4(1)(b)), and to "[c]ooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification,

95. *See* Diana Reckien et al., *Navigating the Continuum Between Adaptation and Maladaptation*, 13 Nature Climate Change 907, 908 (2023), https://doi.org/10.1038/s41558-023-01774-6.

96. U.N. Framework Convention on Climate Change, *supra* note 7, at 169–70.

as well as floods" (Article 4(1)(e)).[97] Then in Article 4(4), it called on "developed country Parties . . . [to] assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects," and established a financial mechanism in Article 11.[98]

The Kyoto Protocol also said little about adaptation compared with its extensive attention to mitigation. In Article 10(b) (echoing FCCC Article 4(1)(b)), it called for parties to "[f]ormulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change . . . ."[99] And in a new effort to find funding for adaptation, in Article 12(8), it provided that "a share of the proceeds from certified project activities" in the CDM should be used "to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation."[100]

Under these provisions of the FCCC and the Kyoto Protocol, and the Nairobi Work Programme on Adaptation and Resilience, several countries have adopted National Adaptation Plans.[101] In the United States, some of the trillions in infrastructure spending under the Bipartisan Infrastructure Law and the Inflation Reduction Act will go to adaptation.[102] Parties have made financial commitments through mechanisms such as the Global Environmental Facility (GEF) and the Green Climate Fund created after the 2009 Copenhagen COP15—at which a goal was announced of mobilizing $100 billion per year for developing countries by 2020, from a variety of sources (including both mitigation and adaptation)—a goal which has not yet been attained.[103] The Paris Agreement added significant focus on adaptation in Article 7—a

97. *Id.* at 170–71.
98. *Id.* at 173, 179.
99. Kyoto Protocol, *supra* note 8, art. 10(b).
100. *Id*. art. 12(8).
101. *See Climate Adaptation*, United Nations, https://www.un.org/en/climatechange/climate-adaptation [https://perma.cc/XV35-896F]; *National Adaptation Plans*, U.N. Climate Change, https://www4.unfccc.int/sites/NAPC/Pages/national-adaptation-plans.aspx [https://perma.cc/KEY7-939K]. The Nairobi Work Programme on Adaptation and Resilience was adopted in 2005 under the UN FCCC. *See* UNFCCC. Secretariat, Overview of the Nairobi Work Programme (July 20, 2018).
102. *See* Savannah Bertrand, *How the Inflation Reduction Act and Bipartisan Infrastructure Law Work Together to Advance Climate Action*, Env't & Energy Study Inst. (Sept. 12, 2022), https://www.eesi.org/articles/view/how-the-inflation-reduction-act-and-bipartisan-infrastructure-law-work-together-to-advance-climate-action [https://perma.cc/8UGA-HZ7R].
103. *See generally* Green Climate Fund, https://www.greenclimate.fund/ [https://perma.cc/S725-MAUR] (summarizing the Green Climate Fund); Richard Kozul-Wright, *A Climate Finance Goal That Works for Developing Countries*, United Nations Conf. on Trade & Dev. (June 14, 2023), https://unctad.org/news/climate-finance-goal-works-developing-countries [https://perma.cc/SPX2-7AAZ] (discussing shortcomings of $100 billion goal and discussions on a new approach).

full article calling on parties to undertake and cooperate on adaptation actions and to communicate periodically on these efforts.[104] The global stocktakes under Articles 7(14) and 14 also include assessments of adaptation efforts.[105] At the 2021 Glasgow COP26, parties launched the Global Goal on Adaptation[106] and committed to double the funding for adaptation in developing countries.[107]

In addition, the Paris Agreement recognized the issue of loss & damage for past or ongoing climate damages in Article 8,[108] but paragraph 52 of the decision adopting the Paris Agreement qualified that "Article 8 of the Agreement does not involve or provide a basis for any liability or compensation[.]"[109] The Warsaw International Mechanism (referenced in Article 8(2)) was established at COP19 in 2013 to address loss and damage associated with impacts of climate change in particularly vulnerable developing countries. By COP27 in 2022, the United States and EU agreed to set up a financial mechanism for loss & damage.[110]

C. *Reflection*

As efforts on mitigation and adaptation have been slow, a third possible (and controversial) strategy for addressing global climate change has been gaining attention: reflecting some of the Sun's energy from heating the Earth.[111] As climate impacts worse, reflection may rise on the future policy agenda. These techniques are often called solar geoengineering, solar radiation modification, or sunlight reflection methods (SRM)—such as emulating volcanoes by injecting reflective sulfate aerosol particles into the stratosphere.[112]

104. Paris Agreement, *supra* note 9, art. 7, paras. 1–3.

105. *Id.* arts. 7, para. 14(c)–(d), 14, para. 1.

106. *See Introduction: Adaptation and Resilience*, United Nations Framework Convention on Climate Change, https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/introduction [https://perma.cc/L7U3-95KW].

107. *See COP 26: Together for Our Planet*, United Nations, https://www.un.org/en/climatechange/cop26 [https://perma.cc/3RXT-Y83J].

108. Paris Agreement, *supra* note 9, art. 8, para. 1.

109. Framework Convention on Climate Change Draft Decision -/CP.21, FCCC/CP/2015/L.9, at 52 (Dec. 11, 2015).

110. Press Release, Framework Convention on Climate Change, COP27 Reaches Breakthrough Agreement on New "Loss and Damage" Fund for Vulnerable Countries (Nov. 20, 2022), https://unfccc.int/news/cop27-reaches-breakthrough-agreement-on-new-loss-and-damage-fund-for-vulnerable-countries [https://perma.cc/ZC46-EAWB].

111. See Intergovernmental Panel on Climate Change, *supra* note 1, at 1022–23 (on geoengineering); Nat'l Acads. of Sci., Eng'g & Med., Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance 1 (2021), https://doi.org/10.17226/25762 [hereinafter NASEM: Reflecting Sunlight] (explaining several techniques for SRM and their pros and cons); Aldy & Zeckhauser, *supra* note 4, at 14 (referring to sunlight reflection methods as a "third" strategy).

112. *See* NASEM: Reflecting Sunlight, *supra* note 111, at 34.

The IPCC addressed SRM and its governance in its Fifth Assessment Report in 2014.[113] But neither the FCCC, nor the Kyoto Protocol, nor the Paris Agreement mentions SRM or solar geoengineering. The adoption of temperature targets in the Paris Agreement,[114] without explicitly addressing SRM, implicitly expanded the array of candidate policy instruments to include interventions that limit temperature directly, in addition to the FCCC's call for policies that mitigate emissions to stabilize concentrations of GHGs in the atmosphere to prevent dangerous climate change.[115] Some past treaties might address SRM, such as the Environmental Modification (ENMOD) Convention[116], the UN Convention on the Law of the Sea (UNCLOS), the Convention on Biological Diversity (CBD),[117] or others. But none of these speak directly to SRM. For example, the ENMOD Convention restricts "hostile" environmental modification[118] whereas deployment of SRM might be defended as intended to be benevolent (although perhaps rogue deployment, or disregard of adverse impacts, of SRM could be deemed "hostile"). For now, there may be no adequate existing governance institutions for SRM.[119]

On September 14, 2023, the recently established Climate Overshoot Commission (COC) released its report, addressing mitigation (both emissions reductions and CDR), adaptation, and reflection.[120] As to reflection (SRM), which the COC hopes would not be needed, the

113. *See* Intergovernmental Panel on Climate Change, *supra* note 1, at 1022–23 (describing geoengineering methods including SRM).

114. Paris Agreement, *supra* note 9, art. 2 (referring to 2.0° or even 1.5°C).

115. U.N. Framework Convention on Climate Change, *supra* note 7, at 166–68.

116. United Nations Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, Dec. 10, 1976, 1108 U.N.T.S. 152 [hereinafter Convention on Environmental Modification].

117. United Nations Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 143.

118. Convention on Environmental Modification, *supra* note 116, art. I.

119. *See* Tyler Felgenhauer et al., Solar Radiation Modification: A Risk-Risk Analysis (2022), https://www.c2g2.net/wp-content/uploads/202203-C2G-RR-Full.pdf [https://perma.cc/ARP9-77BT]; Jesse L. Reynolds, The Governance of Solar Geoengineering: Managing Climate Change in the Anthropocene 5 (2019), https://doi.org/10.1017/9781316676790; Michael Burger & Justin Gundlach, *Research Governance*, *in* Climate Engineering and the Law: Regulation and Liability for Solar Radiation Management and Carbon Dioxide Removal 269 (Michael B. Gerrard & Tracy Hester eds., 2018), https://doi.org/10.1017/9781316661864; Edward A. Parson & Lia N. Ernst, *International Governance of Climate Engineering*, 14 Theoretical Inquiries L. 307, 317–18 (2013). For a suggestion that the UN Security Council could be a key institution for governing SRM, see Susan Biniaz & Daniel Bodansky, Solar Climate Intervention: Options for International Assessment and Decision Making 1 (2020).

120. *See generally* Climate Overshoot Comm'n, Reducing the Risks of Climate Overshoot 10 (2023), https://www.overshootcommission.org/_files/ugd/0c3b70_bab3b3c1cd394745b387a594c9a68e2b.pdf [https://perma.cc/V2UG-WXE3] [hereinafter COC] (describing methods to prepare for climate overshoot). The COC, convened by the Paris Peace Forum, is composed of leaders from governments, academia and non-governmental organizations around the world (speaking in their personal capacities). *Id.*

report called for a moratorium by states on deployment and large-scale outdoor experiments posing risk of significant transboundary harm (to prevent premature deployment and to reduce potential relaxation of mitigation efforts), and it also called for expanded research on SRM (in order to learn more about its pros and cons, so that future decisions on SRM could be better informed).[121] The COC report recognized the potential for serious risk-risk tradeoffs from SRM,[122] such as delayed recovery of the ozone layer, acid rain, regionally harmful climate impacts, weakening mitigation efforts, "termination shock," and international conflict over unilateral use.[123] At the same time, the COC recognized that not researching SRM could pose its own risks of climate overshoot damages or poorly informed decisions.[124] It called for an independent international scientific review of SRM every few years, possibly by the IPCC, the World Meteorological Organization (WMO), or the United Nations Environment Programme (UNEP).[125]

The COC report observed that "there is no legally binding governance mechanism dedicated to SRM."[126] It recognized the governance challenges of reaching international agreement on SRM decisions with global participation to prevent the risk-risk tradeoffs just noted.[127] It urged the moratorium on deployment to remain in effect until knowledge and governance have adequately advanced.[128] It left for another day the specific institutional mechanisms to embody its recommendations in the international climate regime. For example: What institutional arrangements would encourage national governments to adopt and adhere to such a moratorium on deployment? How might non-state actors be addressed? What response measures would be appropriate if there were unilateral deployment of SRM? What institution would decide on any changes or exceptions to the deployment moratorium (e.g., in case of emergency need for SRM)? How would the expanded research be conducted, shared, and translated into policy decisions? The COC emphasized the "urgent need to begin international consultations" on these issues,[129] not toward immediate formal legal action but toward better knowledge, capacity, norm development, and trust, so that future intergovernmental

---

121. *Id.* at 92–93. The COC qualified that SRM research should be led by governments with effective environmental regulatory systems, in North-South partnerships, and not by for-profit firms (such as fossil fuel companies). *Id.*
122. *See* FELGENHAUER ET AL., *supra* note 119, at 2–3.
123. COC, *supra* note 120, at 87–91.
124. *Id.* at 87, 89–90.
125. *Id.* at 92, 94.
126. *Id.* at 90.
127. *Id.* at 90–91.
128. *Id.* at 92.
129. *Id.* at 91.

decisions can better address risk tradeoffs, precaution, justice, and legitimacy.[130]

D. *Summary and Comments on Regime Evolution*

Table 1 summarizes the preceding discussion on the evolution of the key policy designs in the international climate regime. In general, most efforts so far have been aimed at mitigation (though its pace has been slow). Within mitigation, the policy designs have exhibited varying attempts to apply *targets (*or *goals)* to limit national emissions, covering a comprehensive *scope* of multiple GHGs, sources, and sinks, while increasing the use of *flexibility* mechanisms from informal toward more formal and more widespread emissions trading systems (ETS), and with some elements of *adaptive learning* over time. In contrast to earlier periods, there is now increasing attention to adaptation in the international regime. And there has been rising attention but little international governance applicable to SRM.

We have discussed several factors above that may explain the observed patterns of mitigation (and its policy instruments), adaptation, and reflection. These include efforts to design comprehensive and cost-effective climate policy instruments, but strong incentives for free riding, heterogeneous interests and capacities across countries, slow progress on mitigation, and worsening impacts of climate change. Another factor that might elevate mitigation, adaptation, and particularly reflection on the policy agenda is the potential for "focusing events" to spur action. Crises and surprises, tipping points with high damages (such as wildfires, extreme storms, and deadly heat waves), and associated "policy shocks" to governments, may galvanize public outcry and open windows of opportunity for policy entrepreneurs.[131] If climate change damages, such as heat wave deaths, wildfire disasters, super storms, or major sea level rise become more frequent and/or more severe, the acute suffering may spur outcry for new policy actions—potentially in mitigation, adaptation, and/or reflection. For example, a country suffering a devastating heat wave with millions of deaths might turn to desperate measures, including potential unilateral deployment of SRM.[132]

Of course, no single causal factor shapes climate policy making. Public opinion is influenced not only by the perceived risk of climate harms,

---

130. *Id.* at 94.

131. *See* POLICY SHOCK: RECALIBRATING RISK AND REGULATION AFTER OIL SPILLS, NUCLEAR ACCIDENTS AND FINANCIAL CRISES (Edward J. Balleisen et al. eds., 2017); THOMAS A. BIRKLAND, LESSONS OF DISASTER: POLICY CHANGE AFTER CATASTROPHIC EVENTS (2006).

132. *See* Antonia Eliason, *Avoiding Moonraker: Averting Unilateral Geoengineering Efforts*, 43 U. PA. J. INT'L L. 429, 429–67 (2022), http://dx.doi.org/10.2139/ssrn.3811361. This scenario is also depicted in the novel by Kim Stanley Robinson. KIM STANLEY ROBINSON, MINISTRY FOR THE FUTURE (2020).

but also by the perceived relative attractiveness of policy responses.[133] Successful climate action may involve coalitions of both climate advocates ("baptists") and industry rent-seekers ("bootleggers").[134] As to the potential establishment of national SRM research programs, "multiple streams analysis" suggests that these efforts are likely to gain momentum if advocacy coalitions emerge, both in the United States[135] and comparing across the United States, Australia, China, and Germany.[136] Though they may be opposed by other interest groups, these coalitions may also grow with the continued evolution of domestic public opinion and politics of climate change, and might be catalyzed by intense crises or focusing events such as acute climate damages.

133. *See* Troy H. Campbell & Aaron C. Kay, *Solution Aversion: On the Relation Between Ideology and Motivated Disbelief*, 107 J. Personality & Soc. Psych. 809, 809 (2014), https://doi.org/10.1037/a0037963.

134. *See* Wiener & Richman, *supra* note 2, at 377; Adam Smith & Bruce Yandle, Bootleggers and Baptists: How Economic Forces and Moral Persuasion Interact to Shape Regulatory Politics, at vii (2014). For mitigation, such coalitions could enlist both "baptist" advocates for climate protection (and for co-benefits in conventional pollution reduction) and "bootlegger" lobbyists for alternative low- or no-carbon energy sources. For sunlight reflection methods (SRM), such coalitions could enlist both "baptist" advocates for climate protection (especially the victims of peak climate damages) and "bootlegger" lobbyists for those seeking to avoid the costs of mitigation. The COC urged that SRM research "should not be funded by sources with an interest in maintaining greenhouse gas emissions, such as fossil fuel interests." *See* COC, *supra* note 120, at 93.

135. *See* Tyler Felgenhauer et al., *Solar Geoengineering Research on the U.S. Policy Agenda: When Might Its Time Come?*, Env't Pol., June 2021, at 1–2, https://doi.org/10.1080/09644016.2021.1933763.

136. *See* Joshua B. Horton et al., *Solar Geoengineering Research Programs on National Agendas: A Comparative Analysis of Germany, China, Australia, and the United States*, Climatic Change, Mar. 31, 2023, at 1, 2, 15, https://doi.org/10.1007/s10584-023-03516-1.

TABLE 1. KEY CLIMATE POLICY INSTRUMENTS OVER TIME

<u>MITIGATION</u> OF POTENTIAL CLIMATE CHANGE	<u>ADAPTATION</u> TO ONGOING CLIMATE CHANGE	<u>REFLECTION</u> OF SOLAR ENERGY
1990s–2000s		
FCCC (1992): • Targets/goals: stabilize concentrations to avoid dangerous interference; all countries take policies and measures; Annex I countries return to 1990 levels by 2000. • Scope: all GHGs (not covered by MP), sources and sinks • Flexibility: JI • Adaptive learning: framework plus future protocols, reporting, COPs, IPCC reports Kyoto Protocol (1997): • Targets/goals: quantitative emissions limitations for Annex I countries, by around 2010 • Scope: six sets of GHGs, sources and sinks • Flexibility: JI, ETS, CDM • Adaptive learning: reporting, potential 2nd commitment period, IPCC reports	FCCC: Article 4, 11 Kyoto Protocol: Article 10, 12	?

Mitigation of Potential Climate Change	Adaptation to Ongoing Climate Change	Reflection of Solar Energy
2010s–2020s		
Paris Agreement (2015): • Targets/goals: 2.0°/1.5° C global temperature goal; NDCs to limit national emissions • Scope: all GHGs, sources and sinks • Flexibility: Article 6 markets • Adaptive learning: updating NDCs, stocktakes, IPCC reports Kigali Amendment to MP (2016): • Targets/goals: phasedown of HFCs • Scope: adds HFCs to prior MP limits on CFCs, HCFCs • Adaptive learning: Amendments process, Ozone science assessment reports ICAO/CORSIA (2016): • Targets/goals: limiting commercial aviation emissions • Scope: CO2 • Flexibility: CORSIA offset trading market • Adaptive learning: phases	Funding pledges for adaptation, e.g. Green Climate Fund Paris Agreement (2015): • Article 7 on adaptation • Article 8 on Loss & Damage	IPCC 5th and 6th Assessment Reports UNEP report COC report National studies
Toward the 2030s–2050s?		
More ambitious NDCs? Global pledges on Methane and on Deforestation More CDR (CCS, DAC)?	Infrastructure for adaptation; Loss & Damage; Litigation requiring adaptation?	Governance of SRM?

III. The Rise of Reflection?

A. *Rising Interest in Solar Radiation Modification (SRM)*

The history of mitigation and adaptation recounted above, and the growing threat of damages from worsening climate change, have led some to call for greater attention and research on SRM, despite the controversial character of this strategy. As discussed above, political coalitions and crisis or focusing events could elevate SRM on the policy agenda, such as by a country suffering acute climate damages.[137] And as described above, SRM could reduce climate risks, but could also pose countervailing risk-risk tradeoffs.[138] Some scientists have issued a letter calling for a moratorium on SRM research,[139] while others have called for pursuing expanded and balanced research.[140] In the future, if interest in sunlight reflection rises, even if only among a few actors who might proceed unilaterally, the international climate change regime will need to (and should) develop governance mechanisms to address SRM.

Scientific understanding of SRM goes back many decades—as early as 1957.[141] Nobel laureate Paul Crutzen raised the SRM question in 2006,[142] and since then SRM has been featured in several federal climate change reports, such as the Fourth U.S. National Climate Assessment in 2018[143] and its supporting Climate Science Special Report,[144] as well as

---

137. *See supra* Section II.D.

138. *See* Felgenhauer et al., *supra* note 119, at 2; COC, *supra* note 119, at 87–91.

139. *See We Call for an International Non-Use Agreement on Solar Geoengineering*, Solar Geoeng'g Non-Use Agreement, https://www.solargeoeng.org/non-use-agreement/open-letter/ [https://perma.cc/RS7U-DDL9]; Frank Biermann et al., *Solar Geoengineering: The Case for an International Non-Use Agreement*, WIREs Climate Change, Jan. 17, 2022, at 1, https://doi.org/10.1002/wcc.754.

140. *See* Claudia E. Wieners et al., *Solar Radiation Modification Is Risky, but So Is Rejecting It: A Call for Balanced Research*, Oxford Open Climate Change, Mar. 20, 2023, at 1, 3, https://doi.org/10.1093/oxfclm/kgad002; Sarah J. Doherty et al., An Open Letter Regarding Research on Reflecting Sunlight to Reduce the Risks of Climate Change, Jan. 17, 2022, at 1, https://climate-intervention-research-letter.org/ [https://perma.cc/USC7-QTFX].

141. See a full listing in David W. Keith, *Geoengineering the Climate: History and Prospect*, 25 Ann. Rev. Energy & Env't 245, 257–58 tbl.1, 282 (2000), https://doi.org/10.1146/annurev.energy.25.1.245 (including mention of SRM in a report to President Lyndon Johnson in the mid-1960s).

142. Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma? An Editorial Essay*, 77 Climatic Change 211, 212 (2006), https://doi.org/10.1002/2016EF000407.

143. U.S. Glob. Change Rsch. Program, Fourth National Climate Assessment Vol. II: Impacts, Risks, and Adaptation in the United States 1363 (D.R. Reidmiller et al. eds., 2018), https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf [https://perma.cc/ND6M-MMPD].

144. B. DeAngelo et al., *Perspectives on Climate Change Mitigation*, *in* Climate Science Special Report: Fourth National Climate Assessment 393, 401–03 (D. J. Wuebbles et al. eds., 2017), https://science2017.globalchange.gov/downloads/CSSR_Ch14_Mitigation.pdf [https://perma.cc/HT69-MU2E]; Ella Necheles et al., *Funding for Solar Geoengineering from 2008 to 2018*, Harv. Solar Geoeng'g Rsch. Program: SGR Blog (Nov. 13, 2018), https://geoengineering.environment.harvard.edu/blog/funding-solar-geoengineering [https://perma.cc/7QQN-NSSD].

in a recent briefing from the National Intelligence Council.[145] Further, several studies dedicated to SRM have been issued in the past few years. A 2015 report by the National Research Council of the National Academies of Sciences, Engineering, and Medicine (NASEM) called for the creation of a U.S. federal solar geoengineering research program.[146] A follow-on report from NASEM in 2021 also called for such a program, to be overseen by the U.S. Global Change Research Program (USGCRP), with $100–200 million in funding over its first five years to study physical and social science questions including governance of research and the possibility of small-scale outdoor experimentation.[147] A 2023 report from the White House Office of Science and Technology Policy (OSTP) outlined a detailed strategy for such a potential SRM research program, but stopped short of advocating its creation.[148]

The U.S. Congress has held several hearings on SRM over the past decade or more,[149] while the Congressional Research Service addressed the topic in its own report.[150] In fiscal year 2020 (FY20), Congress appropriated $4 million to the National Oceanic and Atmospheric Administration (NOAA) to develop the Earth Radiation Budget program to "investigate natural and human activities which might alter the reflectivity of the stratosphere and the marine boundary layer, and the potential impact of those activities on the Earth system"; this funding rose to $9 million in FY21 and $9.5 million in FY23.[151]

Internationally, attention rose with a 2009 overview report on SRM from the UK Royal Society,[152] and a section of the 2014 report of the

---

145. NAT'L INTEL. COUNCIL, NATIONAL INTELLIGENCE ESTIMATE: CLIMATE CHANGE AND INTERNATIONAL RESPONSES INCREASING CHALLENGES TO US NATIONAL SECURITY THROUGH 2040, at 11 (2021), https://www.dni.gov/files/ODNI/documents/assessments/NIE_Climate_Change_and_National_Security.pdf [https://perma.cc/UUB4-6673].

146. NAT'L ACADS. OF SCI., ENG'G, & MED., CLIMATE INTERVENTION: REFLECTING SUNLIGHT TO COOL EARTH 9–10 (2015), https://doi.org/10.17226/18988 [hereinafter NASEM REFLECTING SUNLIGHT].

147. NAT'L ACADS. OF SCI., ENG'G, & MED., REFLECTING SUNLIGHT: RECOMMENDATIONS FOR SOLAR GEOENGINEERING RESEARCH AND RESEARCH GOVERNANCE 10–11, 13, 16–17 (2021), https://doi.org/10.17226/25762.

148. OFF. OF SCI. & TECH. POL'Y, CONGRESSIONALLY MANDATED RESEARCH PLAN AND AN INITIAL RESEARCH GOVERNANCE FRAMEWORK RELATED TO SOLAR RADIATION MODIFICATION 2–4, 10 (2023), https://www.whitehouse.gov/wp-content/uploads/2023/06/Congressionally-Mandated-Report-on-Solar-Radiation-Modification.pdf [https://perma.cc/5RP7-NB7K].

149. *E.g.*, *Geoengineering: Parts I, II, and III: Hearing Before the H. Comm. on Sci. and Tech.*, 111th Cong. 6 (2010); *Geoengineering: Innovation, Research, and Technology: Joint Hearing Before the Subcomm. on Env't & Subcomm. on Energy, Comm. on Sci., Space, and Tech.*, 115th Cong. 11–12, 24–25 (2017).

150. K. BRACMORT & R. K. LATTANZIO, CONG. RSCH. SERV., R41371, GEOENGINEERING: GOVERNANCE AND TECHNOLOGY POLICY 15–16 (2013), https://crsreports.congress.gov/product/pdf/R/R41371 [https://perma.cc/T2US-HX93].

151. *Earth's Radiation Budget*, NOAA CHEM. SCI. LAB'Y, https://csl.noaa.gov/research/erb/faqs.html [https://perma.cc/VS2J-8FM3].

152. ROYAL SOC'Y, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE, AND UNCERTAINTY ix–x (2009), https://royalsociety.org/~/media/royal_society_content/policy/publications/2009/8693.pdf [https://perma.cc/74HM-SF3Y].

IPCC.[153] UNEP issued a report on SRM in 2023.[154] The European Commission's Group of Chief Scientific Advisors wrote in a Scoping Paper in August 2023 that "interest in some forms of SRM is likely to grow in the future, in case of temperature overshoot due to insufficient mitigation or the risk of climate tipping points being reached," and sought advice on the risks, opportunities, and governance of SRM to be issued in late 2024.[155] Additional recent or forthcoming reports on SRM include draft statements of ethical principles from both the American Geophysical Union (AGU)[156] and the UN Educational Scientific and Cultural Organization (UNESCO) World Commission on the Ethics of Scientific Knowledge and Technology (COMEST),[157] as well as an assessment by the WMO.[158] As discussed above, the Climate Overshoot Commission released its report on September 14, 2023, calling for a moratorium on the deployment of SRM coupled with expanding research on SRM to support future decisions.[159]

B. *Risk-Risk Analysis of SRM*

SRM may be able to reduce climate change risks by quickly slowing or halting the rise in global temperatures, perhaps shielding us from peak climate damages, or even cooling the planet.[160] The benefits would include reduced frequency and intensity of extreme temperature and

---

153. *See* Robert Stavins et al., *International Cooperation: Agreements and Instruments*, *in* Climate Change 2014: Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 1022–23 (Ottmar Edenhofer et al. eds., 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf [https://perma.cc/R8VQ-76H2] (discussing geoengineering and its governance).

154. U.N. Env't Programme, One Atmosphere: An Independent Expert Review on Solar Radiation Modification Research and Deployment (Andrea Hinwood & Jason Jabbour eds., 2023), https://wedocs.unep.org/bitstream/handle/20.500.11822/41903/one_atmosphere.pdf?sequence=3&isAllowed=y [https://perma.cc/GUN8-8BQX].

155. *See* Eur. Comm'n Grp. of Chief Sci. Advisors, Scoping paper: Solar Radiation Modification 4–5 (2023), https://research-and-innovation.ec.europa.eu/system/files/2023-08/Scoping_paper_SRM.pdf [https://perma.cc/9YA7-J5YE].

156. Am. Geophysical Union, Ethical Framework Principles for Climate Intervention Research (tentantive draft 2023), https://www.agu.org/-/media/files/learn-about-agu/ethical-framework-climate-intervention/agu-ethical-framework-draft-principles_277689_.pdf [https://perma.cc/65ZJ-UWBX].

157. World Comm'n on the Ethics of Sci. Knowledge & Tech., Draft Report of the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) on the Ethics of Climate Engineering 3 (2023), https://unesdoc.unesco.org/ark:/48223/pf0000386677/PDF/386677eng.pdf.multi [https://perma.cc/T5HF-LJHX].

158. World Meteorological Org., Scientific Assessment of Ozone Depletion: (2022), https://ozone.unep.org/system/files/documents/Scientific-Assessment-of-Ozone-Depletion-2022.pdf [https://perma.cc/HN7L-MAD3].

159. *See* COC, *supra* note 120, at 8, 15.

160. NASEM: Reflecting Sunlight, *supra* note 111, at 2; Peter Irvine et al., *Halving Warming with Idealized Solar Geoengineering Moderates Key Climate Hazards*, 9 Nature Climate Change 295, 297–98 (2019), https://doi.org/10.1038/s41558-019-0398-8.

precipitation events, reduced heat stress mortality, reduced hurricane intensity, and slowed melting of sea and land ice (which would slow sea level rise).[161] Studies of historical volcanic eruptions that emitted sulfates into the stratosphere provide empirical evidence for how this type of SRM would work.[162]

SRM could also pose several countervailing risks.[163] As we have addressed in greater detail elsewhere,[164] these risk-risk tradeoffs include biophysical risks from injecting sulfate particles in the stratosphere, such as:

- regional climate impacts, especially with respect to precipitation,
- acid deposition,
- stratospheric ozone changes,
- excessive cooling,
- light diffusion and dimming.

And SRM's risk-risk tradeoffs include socio-political risks from actors researching, developing, deploying, or responding to SRM strategically, such as:

- "moral hazard" or mitigation displacement,
- unilateral deployment and international conflict,
- "termination shock."[165]

A comprehensive risk-risk analysis is needed to assess these multiple risks thoroughly and holistically, to reduce overall risk, and to address any residual risks from SRM decisions.[166] Here we mention each of these risks briefly.

161. *See* Irvine et al., *supra* note 160, at 297–98; Felgenhauer et al., *supra* note 118, at 3.

162. *See* NASEM: Reflecting Sunlight, *supra* note 111, at 34.

163. *See* Felgenhauer et al., *supra* note 119, at 2; Benjamin K. Sovacool et al., *Risk-Risk Governance in a Low-Carbon Future: Exploring Institutional, Technological, and Behavioral Tradeoffs in Climate Geoengineering Pathways*, 43 Risk Analysis 838, 838 (2023), https://doi.org/10.1111/risa.13932; Gernot Wagner, Geoengineering: The Gamble 1 (2021).

164. *See* Felgenhauer et al., *supra* note 119, at 7.

165. *See* Andy Parker & Peter J. Irvine, *The Risk of Termination Shock From Solar Geoengineering*, 6 Earth's Future 456, 456–57 (2018), https://doi.org/10.1002/2017EF000735.

166. *See* COC, *supra* note 120; Felgenhauer et al., *supra* note 119; Edward A. Parson, *Geoengineering Research and Climate Risks: Toward Symmetric Precaution*, 374 Science 795, 795 (2021), https://doi.org/10.1126/science.abm8462; Felgenhauer et al., *Practical Paths to Risk-Risk Analysis of SRM* (Mar. 2024) (unpublished manuscript) (on file with author). These risks of SRM would vary with the type of SRM technique; for example, a space-based planetary sunshade would avoid the biophysical risks of injecting sulfur aerosols into the stratosphere, though the sunshade might be more costly and might pose different risks of socio-political problems. *See* Leonard David, *These Scientists Want to Put a Massive 'Sunshade' in Orbit to Help Fight Climate Change*, Space Insider (Dec. 19, 2023), https://www.space.com/sunshade-earth-orbit-climate-change [https://perma.cc/78U4-5N9P]; Planetary Sunshade Foundation, State of Space-Based Solar Radiation Modification 4 (2023).

SRM would not just be unwinding or reversing climate change, but would be layering another type of climate change simultaneous with greenhouse warming, posing complex biophysical effects. Several uncertainties remain in climatological processes and how the climate would respond to an intervention that changes global radiative forcing.[167] For example, regional precipitation patterns may change, harming some local populations, but also benefiting others and potentially reducing some inequities across countries.[168] Sulfate aerosols injected into the stratosphere could adversely affect the ozone layer that shields the Earth from ultraviolet (UV) radiation.[169] The sulfate particles would precipitate out after about eighteen months to two years, yielding acid deposition and also necessitating continual injections to sustain SRM.[170] Excessive cooling from SRM—causing near-term climate harms—could occur if SRM were more effective than expected, if it were deployed more than needed, or if a large volcano erupted during SRM deployment.[171]

Strategically, one concern is that if SRM promises to alleviate climate damages, then its prospect—even before it were deployed—might pose incentives to relax or weaken mitigation efforts—sometimes called "moral hazard" or "mitigation displacement."[172] Interestingly, some experimental studies find the opposite—that mitigation effort increases (not decreases) when SRM is introduced in a multiplayer game.[173] In practice, this counterintuitive result might be due to players perceiving the introduction of SRM as a signal that the climate problem is even more dire, hence warranting greater mitigation effort even if SRM is also used; or, it might be due to players fearing that SRM would pose its own countervailing risks, hence warranting greater mitigation effort to

167. *See* WALKER RAYMOND LEE ET AL., SUNLIGHT REFLECTION MANAGEMENT PRIMER (2021), https://www.srmprimer.org/the-primer [https://perma.cc/WK4F-SAZ6].

168. Anthony R. Harding et al., *Climate Econometric Models Indicate Solar Geoengineering Would Reduce Inter-Country Income Inequality*, NATURE COMMC'NS, Jan. 13, 2020, at 1, 6, https://doi.org/10.1038/s41467-019-13957-x.

169. *See generally* Simone Tilmes et al., *Sensitivity of Total Column Ozone to Stratospheric Sulfur Injection Strategies*, GEOPHYSICAL RESEARCH LETTERS, Sept. 2021, https://doi.org/10.1029/2021GL094058.

170. *See* FELGENHAUER ET AL., supra note 119, at 19, 28.

171. *Id*. at 28.

172. *See* Albert C. Lin, *Does Geoengineering Present a Moral Hazard?*, 40 ECOLOGY L.Q. 673, 673 (2013); Stephen M. Gardiner, *Geoengineering: Ethical Questions for Deliberate Climate Manipulators*, *in* THE OXFORD HANDBOOK OF ENVIRONMENTAL ETHICS 501 (Stephen M. Gardiner & Allen Thompson eds., 2017); Ben Hale, *The World That Would Have Been: Moral Hazard Arguments Against Geoengineering*, *in* ENGINEERING THE CLIMATE: THE ETHICS OF SOLAR RADIATION MANAGEMENT 113 (Christopher J. Preston ed., 2012).

173. *See* Todd Cherry et al., *Climate Cooperation in the Shadow of Solar Geoengineering: An Experimental Investigation of the Moral Hazard Conjecture*, 32 ENV'T POL. 362 (2023), https://doi.org/10.1080/09644016.2022.2066285; Todd Cherry et al., *Does Solar Geoengineering Crowd out Climate Change Mitigation Efforts? Evidence from a Stated Preference Referendum on a Carbon Tax*, CLIMATIC CHANGE, 2021, at 1, https://doi.org/0.1007/s10584-021-03009-z.

dissuade others from using SRM.[174] Some other studies find little or no effect of SRM on mitigation in either direction.[175]

A second strategic concern is unilateral deployment and international conflict. The incentives for SRM deployment may be the converse of the incentives for mitigation: rather than a "free rider" incentive to wait for others to bear the cost of reducing emissions, there may be a "free driver" incentive to be the first mover on SRM.[176] A country facing acute climate damages and suffering might be motivated to deploy SRM unilaterally. Countries likely have heterogeneous preferences regarding the optimal global temperature, and they would face heterogeneous expected impacts from climate change and from SRM.[177] Unilateral deployment of SRM could induce international conflict over SRM—such as countermoves to modify the climate in the opposite direction, or military attacks on the SRM project—as well as the other biophysical and socio-political risks of SRM.[178] If so, then governance institutions, while mobilizing collective efforts on GHG mitigation, would also need to find ways to restrain hasty or unwise unilateral deployment of SRM.[179] Of course, collective decisions to use or restrain SRM could also pose climate risks and countervailing risks.

A third strategic concern is that SRM deployment might be vulnerable to "termination shock"—if SRM were deployed, but then stopped and not restored, while GHGs were still forcing climate warming. The result could be a rapid global temperature rebound to an even higher temperature, posing higher damages.[180]

These risk-risk tradeoffs require careful and comprehensive analysis, and they emphasize the need for a good international governance regime.[181] As discussed above, mitigation and adaptation measures also

---

174. *See* Aldy & Zeckhauser, *supra* note 4, at 3–4 ("SRM deployment might even serve as an 'awful action alert' that galvanizes more ambitious emission mitigation.").

175. *See* Christine Merk & Gernot Wagner, *Presenting Balanced Geoengineering Information Has Little Effect on Mitigation Engagement* 1 (CESifo, Working Paper No. 10104, Nov. 2022), http://dx.doi.org/10.2139/ssrn.4291738; Philipp Schoenegger & Kian Mintz-Woo, *Moral Hazards and Geoengineering: Evidence from a Large-Scale Online Experiment* 1 (July 8, 2023) (unpublished manuscript) (on file with EarthArXiv), https://doi.org/10.31223/X52383.

176. *See* Intergovernmental Panel on Climate Change, *supra* note 1, at 1023. On the term "free driver," see Martin L. Weitzman, *A Voting Architecture for the Governance of Free-Driver Externalities, with Application to Geoengineering*, 117 Scandinavian J. Econ. 1049 (2015), https://doi.org/01.1111/sjoe.12120. See also the classic paper by Scott Barrett, *The Incredible Economics of Geoengineering*, 39 Env't & Res. Econ. 45, 50 (2008) https://doi.org /10.1007/s10640-007-9174-8 (pointing out that the low cost of SRM may invite unilateral use despite the public goods character of the global climate benefits).

177. *See* Harding et al., *supra* note 168, at 4.

178. *See* Intergovernmental Panel on Climate Change, *supra* note 1, at 219.

179. *Id.* at 1023; *see* Felgenhauer et al., *supra* note 119, at 42; Reynolds, *supra* note 119, at 5; Burger & Gundlach, *supra* note 119, at 24; Parson & Ernst, *supra* note 119, at 307; Barrett, *supra* note 176, at 53.

180. *See* Parker & Irvine, *supra* note 165, at 456.

181. *See* COC, *supra* note 120, at 10; Felgenhauer et al., *supra* note 119, at 41, 44;

pose their own risk-risk tradeoffs. They are governed, more or less, by international agreements such as the FCCC and the Paris Agreement and by national regulatory systems for each type of risk. But SRM and its risks seem not yet covered by an international regime. Perhaps the ENMOD Convention (prohibiting "hostile" environmental modification) and Article 4(1)(f) of the FCCC (calling for impact assessments of climate response measures) (and even the mechanism on loss & damage) could be invigorated to offer some remedy for the risk-risk tradeoffs of SRM. But a new international regime, or addition to an existing regime, is needed to govern SRM more broadly.[182]

C. *Reflection on Reflection—Toward Adaptive Governance for SRM*

The potential use of SRM as a climate change risk reduction response presents a design problem with multiple objectives; multiple design parameters; and constraints, tradeoffs, and synergies among different deployment choices.[183] As it is an untried and emerging technology, the possible use of SRM would be a global-scale experiment in which optimal decision-making would involve a repeated Bayesian process of acting, learning about the effects of the action and thus reducing uncertainty, and then acting again in a revised fashion based on the new information. In short, reflection (of sunlight) will necessitate reflection (analysis, review and revision over time).

Some volcanic eruptions emit a large pulse of reflective particles to the stratosphere which in turn cools the Earth quickly.[184] In contrast, a plausible "optimal" deployment of SRM would start gradually and ramp up over a decade or multiple decades as a fleet of newly developed airplanes is built and put into service.[185] A gradual ramp up of SRM would allow for learning and revisions of deployment decisions. Such a learning process could continue throughout the course of any

Parson, *supra* note 166, at 795; Parson & Ernst, *supra* note 119, at 307. Critics of overreliance on risk-risk analysis nonetheless agree that it should be used (with a broad scope and symmetric rigor) to inform, not replace, the development of inclusive governance institutions for SRM. *See* Duncan McLaren, *Governing Emerging Solar Geoengineering: A Role for Risk-Risk Evaluation?*, 24 Geo. J. Int'l Affairs 234, 238—240 (2023), https://doi.org/10.1353/gia.2023.a913651.

182. *See* Felgenhauer et al., *supra* note 119, at 31 (governance challenges and options); Reynolds, *supra* note 119, at 5; Burger & Gundlach, *supra* note 119, at 24; Parson & Ernst, *supra* note 119, at 307.

183. *See* Ben Kravitz et al., *Geoengineering as a Design Problem,* 7 Earth Sys. Dynamics 469, 469–97 (2016), http://doi.org/10.5194/esd-7-469-2016; Yan Zhang et al., *How Large Is the Design Space for Stratospheric Aerosol Geoengineering?*, 13 Earth Sys. Dynamics 201, 202 (2022), https://doi.org/10.5194/esd-13-201-2022.

184. *See How Volcanoes Influence Climate*, UCAR Ctr. for Sci. Educ., https://scied.ucar.edu/learning-zone/how-climate-works/how-volcanoes-influence-climate#:~:text=-Sulfur [https://perma.cc/PJR3-KHZT].

185. Wake Smith, *The Cost of Stratospheric Aerosol Injection Through 2100*, Env't Rsch. Letters, Oct. 2020, at 7, https://doi.org/10.1088/1748-9326/aba7e7.

deployment.[186] This process of acting, learning, and then acting again already occurs in the pre-development research phase, as knowledge is acquired on whether to pursue geoengineering at all.[187] Research can also help to prioritize attention for some approaches and stop investigation of other approaches found to be infeasible or too risky, with research "offramps."[188] One challenge for such adaptive SRM deployment decisions is that the smaller the SRM project, the longer it would likely take before its signal (effect on climate) could be distinguished from the noise of background climate variability, whereas the larger the SRM project, the larger its expected effects (both benefits and risks).

If SRM were deployed (whether collectively or unilaterally), and if its climatic effects could be distinguished separately from ordinary climate variability, a key question is how easily the deployment could be adjusted—how well can it incorporate adaptive policy learning? Once deployed, can the SRM global thermostat be adjusted over time—not only technically, but also institutionally (nationally or through some type of process for countries to agree collectively)? Each stage in SRM development could be assessed in sequence (e.g., computer modeling research, limited field research, small-scale deployment, large-scale deployment), but if the extent of SRM grew larger, both the environmental and sociopolitical effects might increase, and the degree of any political path dependency might increase (that is, if SRM displaces or crowds out other policy options—which as noted above, it may not). A gradual ramp up of SRM, and the short time that sulfate aerosols reside in the stratosphere (roughly two years) could make adaptive adjustments possible in principle, as long as the effects are being monitored and assessed. Still, adjustments could be difficult because of the challenges of detection and attribution, as well as political dependence on SRM.[189] Of course, we need to compare these scenarios to the climate change from emitting GHGs (likely to be long-lasting) and the other impacts from the adoption of mitigation measures (e.g., transitioning to a new energy system). Even if adjusting SRM were difficult and contentious, one must still ask whether accurately adjusting it would be easier—or harder—than removing GHGs from the atmosphere (through CDR) to forestall the equivalent climate impacts. Or, if it were easier or harder than rapidly switching to wind, solar, or nuclear (fission or

186. Douglas G. MacMartin et al., *Technical Characteristics of a Solar Geoengineering Deployment and Implications for Governance*, 19 CLIMATE POL. 1325, 1326 (2019), https://doi.org/10.1080/14693062.2019.1668347.

187. Martin F. Quaas et al., *Are There Reasons Against Open-Ended Research into Solar Radiation Management? A Model of Intergenerational Decision-Making Under Uncertainty*, J. ENV'T ECON. & MGMT, July 2017, http://dx.doi.org/10.1016/j.jeem.2017.02.002.

188. Michael S. Diamond et al., *To Assess Marine Cloud Brightening's Technical Feasibility, We Need to Know What to Study—and When to Stop*, PROC. NAT'L ACAD. SCIS., Jan. 19, 2022, https://doi.org/10.1073/pnas.2118379119.

189. MacMartin et al., *supra* note 186.

fusion). In a portfolio approach,[190] one must ask: what is the optimal timing of combinations or phases of these several approaches to prevent peak climate damages in the short term while ensuring longer-term well-being?

These considerations about risk-risk tradeoffs and adaptive learning suggest that a key goal for governing SRM (as for the climate regime overall) should be *information*—the monitoring needed to detect and assess any preparation and deployment of SRM, novel techniques of SRM, and multi-risk outcomes of SRM. The Paris Agreement added important provisions on monitoring, reporting, and verification (MRV).[191] Monitoring of SRM would need to match its methods and impacts. Thus, the COC report calls for expanded research and periodic assessments to build knowledge on SRM.[192] Impact assessments under FCCC Article 4(1)(f) could offer ex ante forecasts of expected outcomes, and then adaptive learning would involve real-time and ex post monitoring of actual performance, to compare to those ex ante forecasts and options for policy improvement. This monitoring would help give early warnings of activities on the ground and in the air, in preparation for potential SRM testing or deployment, as well as help assess stratospheric changes due to injections of sulfate aerosols or other particles. And it should be equipped to assess a broad, comprehensive scope of SRM impacts, including unintended (ancillary risk and risk-risk tradeoff) impacts as well as target impacts.[193] The system of monitoring should be designed and set up in advance of any deployment in order to deter unilateral action, and enable adaptive learning for any collective use of SRM.[194] Such a monitoring system—especially early notification or warning of impending SRM efforts, and later attribution of SRM impacts—could help avoid geopolitical conflicts over suspected deployments of SRM and adverse impacts, and deter unilateral deployment by ensuring transparent awareness by the international community.

The international climate change regime has evolved slowly despite worsening global warming. It has focused on mitigation, but has made only partial progress toward the 2.0° or 1.5° temperature goals.[195] It has

190. *See* Aldy & Zeckhauser, *supra* note 4, at 3.
191. Paris Agreement, *supra* note 9, art. 7, para. 9(d); Wiener, *supra* note 90.
192. *See* COC, *supra* note 120, at 87–94.
193. *See* Wiener, *supra* note 90.
194. *See* Sébastien Philippe, *Monitoring and Verifying the Deployment of Solar Geoengineering*, *in* Governance of the Deployment of Solar Geoengineering 71, 71 (2019), https://geoengineering.environment.harvard.edu/files/sgrp/files/harvard_project_sg_governance_briefs_volume_feb_2019.pdf [https://perma.cc/M5BD-QH2K]. Through the Duke Center on Risk and partners, we held workshops on SRM monitoring in Wyoming in October 2022 and April 2023, and our colleague, Jessica Seddon, presented our group's early thoughts on SRM monitoring at the conference on Governance of Emerging Technologies and Science (GETS) at Arizona State University in May 2023.
195. *See* Emissions Gap Report 2022, *supra* note 70, at 32.; Plumer, *supra* note 78; Climate Council, *supra* note 78.

recently begun to address adaptation more significantly. But reflection (SRM) remains under-attended in the climate change regime and in related treaties. No international governance regime yet exists for SRM.[196]

New governance mechanisms are needed to address SRM—to ensure collective rather than unilateral decisions, and to remedy countervailing risks. This will not be easy. We suggest that the key elements of such SRM governance should be designed now, in light of research on the benefits and risks of SRM, before unilateral deployment might occur, and then adjusted through a process of adaptive learning. And we suggest that one of the most urgent initial components of such an international governance regime for SRM should be the development of a monitoring and information sharing system—in order to offer early notice of any SRM activities, avoid international conflict through transparency, deter unwise unilateral deployment, assess the climatic and other environmental impacts of SRM, and inform adaptive learning over time. Such an SRM monitoring regime can develop at the same time that the focus of current efforts remains on mitigation and adaptation. It can help assess a research program on SRM. And if SRM deployment (by collective decision) were ever needed to avoid peak climate damages, such a monitoring system would be crucial to assess outcomes, avoid countervailing risks, attribute residual risks, assist those adversely affected, and learn to improve the system adaptively over time.

196. *See* COC, *supra* note 120, at 90; Reynolds, *supra* note 119, at 5; Burger & Gundlach, *supra* note 119, at 24; Parson & Ernst, *supra* note 119, at 307; Felgenhauer et al., *supra* note 119.