USING LEGAL PRINCIPLES TO GUIDE GEOENGINEERING DEPLOYMENT

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As the planet continues to warm, geoengineering has garnered increasing interest. Indeed, scientists have concluded that the likelihood we will need to deploy some form of climate engineering is increasing. However, little attention has been directed to determining an objective set of recognized principles that might guide a deployment decision among various geoengineering technologies.

This Article identifies and reviews several legal principles that decision makers could apply when deciding which geoengineering method to utilize. The Article then determines which principles would be most helpful. These principles—cost-benefit analysis, consideration of alternatives, intergenerational equity, regional equity, reversibility of consequences, and containment of effects—are then prioritized. Finally, the Article applies these principles to several of the most promising climate engineering technologies.

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INTRODUCTION

Climate change will be unavoidable, long-lasting, and potentially catastrophic. While mitigation is critical, it is no longer sufficient to enable us to avoid many of the consequences of climate change. Not surprisingly, many nations and their scientists are beginning to study the feasibility of engineering the climate. Indeed, earlier this year, the United States National Research Council concluded that the likelihood society will need to deploy some form of geoengineering is increasing.[1] Nevertheless, no one has begun determining what principles society should apply when deciding how to deploy geoengineering.

This Article identifies and reviews legal concepts that can inform this decision. Then, this Article determines which legal principles should be used and which can be discarded. Next, it applies decision-making theories to determine the best approach to utilize these principles. With this background, this Article proposes a prioritization of the principles: 1) cost-benefit analysis, 2) consideration of alternatives, 3) intergenerational equity, 4) regional equity, 5) reversibility of consequences, and 6) containment of effects. Finally, it demonstrates the value of the principles by applying them to some of the most promising climate engineering technologies to determine, based upon present information, which would be the most acceptable to deploy.

I. HUMANS ARE CAUSING SEVERE DAMAGE TO THE CLIMATE, BUT GEOENGINEERING CAN HELP AVOID THE WORST CONSEQUENCES OF CLIMATE CHANGE

Anthropogenic emissions of greenhouse gases are causing a rapid warming of the planet. Even though the planet is nearing significant climate tipping points, these emissions are on track to continue for decades; their consequences, however, will last for centuries. To minimize these consequences, society is beginning to consider engineering the climate. Climate engineering presents the promise of minimizing climate change's worst consequences. Many argue, however, that the consequences of these technologies will far exceed any benefits they might provide. Thus, principles need to be identified that can assist decision makers in determining

1 *See* NAT'L RESEARCH COUNCIL, CLIMATE INTERVENTION: REFLECTING SUNLIGHT TO COOL EARTH 5 (2015) [hereinafter NRC REPORT].

which technology to deploy.

A. *Severe Climate Change Is Unavoidable*

Emissions of greenhouse gases have increased significantly since the beginning of the Industrial Revolution. Indeed, the concentration of several greenhouse gases has more than doubled since pre-industrial times.[2] More distressing, the increase in the most prominent of these gases—carbon dioxide—is accelerating. In 2013, the annual increase in carbon dioxide was the largest in three decades.[3]

At their current rate, these emissions will cause significant climate change. A number of natural systems are already demonstrating the effects. For instance, 2014 was the hottest year on record.[4] In addition, the four hottest years on record (2015, 2014, 2010, and 2005) all occurred during the past ten years.[5] The global average sea level has risen steadily since 1900, and this rise is accelerating.[6] Ocean acidification is measurable and occurring at the fastest rate in the past 300 million years.[7]

The consensus of the international community has been that we must hold global warming below two degrees Celsius to avoid

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2 Since 1750, the concentration of carbon dioxide has increased 142%, nitrous oxide by 121%, and methane by 253%. World Meteorological Org., *The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2013*, WMO GREENHOUSE GAS BULLETIN (Sept. 9, 2014), http://library.wmo.int/opac/index.php?lvl=notice_display&id=16396#.VlHsC7_UUhn [hereinafter WMO].

3 *Id.*

4 *See* Nat'l Ctr. for Envtl. Info., *Global Analysis* (Dec. 2015), http://www.ncdc.noaa.gov/sotc/global/201513 (noting that not only was 2015 the hottest year recorded, it also broke the previous record by the largest margin ever, and it was the first year in which each month exceeded its respective average by at least 1°C. In 2015, the planet's monthly temperature average was 0.90°C (1.62°F) warmer than the 20th century average.

5 *See* Justin Gillis, *2014 Breaks Heat Record, Challenging Global Warming Skeptics*, NEW YORK TIMES (Jan. 16, 2015), http://www.nytimes.com/2015/01/17/science/earth/2014-was-hottest-year-on-record-surpassing-2010.html?_r=0 (quoting Tefan Rahmstorf, Head of Earth System Analysis at the Potsdam Institute for Climate Impact Research).

6 *See* N.L. Bindoff et al., *2007: Observations: Oceanic Climate Change and Sea Level*, *in* CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS: CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 409 (Susan Solomon et al. eds., 2007).

7 *See* WMO, *supra* note 2, at 4.

"dangerous climate change."[8] This goal, however, is now "patently unrealistic."[9] Even more troubling, scientists now project the impacts of a 2°C rise to be worse than anticipated. Consequently, scientists now identify such an increase as representing "dangerous" or "extremely dangerous" climate change.[10] Furthermore, scientists calculate that even if we curtail greenhouse gas emissions, global warming will continue to increase for decades.[11] The climate will then remain in its new state for at least 1,000 years.[12]

Thus, our emissions are likely to cause two problems. First, they will alter the planet's climate profoundly. Second, this change will last for generations. Mitigation alone can no longer avert significant climate consequences, nor is mitigation capable of returning the climate to its previous state in less than a millennium. To address these problems, scientists have begun considering climate engineering.

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8 Wil Burns, *Introduction: Climate Change Geoengineering*, 2013 CARBON & CLIMATE L. REV. 87, 87 (2013).

9 *Id; see also* THE WORLD BANK, TURN DOWN THE HEAT: CLIMATE EXTREMES, REGIONAL IMPACTS, AND THE CASE FOR RESILIENCE 1 (2013) (noting that current emission trends and commitments project warming reaching 3.5°C to 5°C by 2100).

10 Kevin Anderson & Alice Bows, *Beyond 'Dangerous' Climate Change: Emission Scenarios for a New World*, 369 PHIL. TRANSACTIONS ROYAL SOC'Y A 20, 23 (2011).

11 *See, e.g.*, H. Damon Matthews & Ken Caldeira, *Stabilizing Climate Requires Near-zero Emissions*, 35 GEOPHYSICAL RES. LETTERS 1, 1 (2008); Intergovernmental Panel on Climate Change, *Summary for Policymakers*, *in* CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS, *supra* note 6, at 12–13 (estimating that if the composition of the atmosphere were to be held constant, the global temperature would still rise by up to 0.9° C by the end of the 21st century).

12 *See* Susan Solomon et al., *Irreversible Climate Change Due to Carbon Dioxide Emissions*, 106 NAT'L ACAD. SCI. 1704, 1705 (2009).

B. *Climate Engineering Can Avoid Climate Change's Worst Effects*

"Climate engineering"[13] refers to a broad range of technologies that might be employed deliberately to alter the Earth's climate system to counter the impacts of climate change.[14] Geoengineering techniques fall into two broad categories.[15] The first, identified as solar radiation management (SRM),[16] would increase the reflection of sunlight to cool the planet.[17] The second, labeled carbon dioxide removal (CDR), would remove CO_2 from the atmosphere.[18] This Article will focus on the former technique.

SRM technologies reflect a small percentage of inbound light and heat from the sun back into space.[19] This is accomplished through a broad range of methods. Surface-based techniques include painting roofs white, planting more reflective crops, or covering desert or ocean surfaces with reflective materials.[20] Atmospheric methods would inject aerosol particles into the atmosphere[21] or increase the reflectivity of clouds (by adding sea

13 Numerous terms besides "climate engineering" have been used to refer to these efforts, including "geoengineering," which appears most frequently. More recently, the NRC used the term "climate intervention," reasoning that it connoted "an action intended to improve a situation," while "climate engineering" implied a greater level of precision than possible. *See generally* NRC REPORT, *supra* note 1, at viii. This Article will use these terms interchangeably.

14 *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: SYNTHESIS REPORT: CONTRIBUTION OF WORKING GROUPS I, II, & III TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 123 (R.K. Pachauri et al. eds., 2014).

15 *See* THE ROYAL SOC'Y, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE, AND UNCERTAINTY ix (2009) [hereinafter ROYAL SOC'Y], http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf (showing use of this distinction in a seminal analysis of geoengineering produced by the United Kingdom's national academy of sciences; subsequent reports including those prepared by a House subcommittee, the NRC, the Intergovernmental Panel on Climate Change, and the Government Accountability Office have followed this dichotomy).

16 Another term used, most prominently in the NRC Report, is "albedo modification." *See* NRC REPORT, *supra* note 1, at 2.

17 *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 98 (Thomas F. Stocker et al. eds., Cambridge Univ. Press 2013) [hereinafter IPCC].

18 *See* NRC REPORT, *supra* note 1, at 2.

19 *See* ROYAL SOC'Y, *supra* note 15, at 29.

20 *See* Peter J. Irvine et al., *Climatic Effects of Surface Albedo Geoengineering*, 116 J. GEOPHYSICAL RES. 1, 2 (2011).

21 *See infra* note 235 and accompanying text.

salt or other materials to whiten clouds).[22] An alternative technology would thin cirrus clouds to allow greater amounts of solar radiation to leave the atmosphere.[23]

C. *Climate Engineering Can Provide Benefits That Other Responses to Climate Change Cannot*

Climate engineering has several advantages over mitigation or adaptation. First, it will cost a fraction of those methods. For instance, at least two geoengineering methods—stratospheric aerosols and cloud whitening—could each cost less than $10 billion per year.[24] When compared to the trillion dollars that mitigation could cost annually,[25] such an alternative is essentially "costless."[26]

Geoengineering could also be much easier to enact. Mitigation requires the compliance of billions of consumers and unprecedented international cooperation.[27] Climate engineering, on

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22 *See infra* note 283 and accompanying text.

23 *See infra* note 305 and accompanying text.

24 Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. & RESOURCE ECON. 45, 49 (2008) ("The Panel [on Policy Implications of Greenhouse Warming] calculated that adding stratospheric aerosol dust to the stratosphere would cost just pennies per ton of CO_2 mitigated."). In a 1994 estimate based upon this analysis, "Nordhaus concluded that offsetting all greenhouse gas emissions today would cost about $8 billion per year." *Id.*; *see also* James Temple, *Cloud Brightening: Theory to Prototype*, S.F. CHRON. (Jan. 5, 2013, 11:01 PM), http://www.sfgate.com/science/article/Cloud-brightening-theory-to-prototype-4170478.php (projecting cloud brightening using seawater to cost as low as $2.5 billion annually). Even persons skeptical of such calculations have acknowledged that the costs of such systems would be "trivial" compared to mitigation approaches. Barrett, *supra*, at 49.

25 *See* Justin McClellan, David W. Keith, & Jay Apt, *Cost Analysis of Stratospheric Albedo Modification Delivery Systems*, 7 ENVTL. RESOURCE LETTERS 034019, at 6 (2012) (estimating that by 2030 the annual cost of mitigation will range from $200 billion to $2 trillion).

26 Barrett, *supra* note 24, at 49. Another estimate is that SRM would have a marginal cost of approximately 1/10,000th of the cost of mitigation. Alan Carlin, *Why a Different Approach Is Required If Global Climate Change Is to Be Controlled Efficiently or Even at All*, 32 WM. & MARY ENVTL. L. & POL'Y REV. 685, 739 (2008).

27 *See* Barrett, *supra* note 24, at 49. For instance, merely stabilizing CO_2 levels would require cutting emissions by 60–80 percent; nevertheless, emissions have risen approximately 20 percent since the adoption of the U.N. Framework Convention on Climate Change. *Id.* While 195 countries, including the U.S. and China, recently agreed to limit global warming to a 2°C threshold, implementation of this goal still requires consent and cooperation. *See, e.g.*, Jeff Goodell, *Will the Paris Climate Deal Save the World?*, ROLLING STONE (Jan. 13,

the other hand, could be implemented by a single state, or even by a single (albeit well-financed) individual.[28]

In addition, SRM could take effect in a matter of months.[29] A major advantage of many SRM technologies is that they may be the only means to reduce the global temperature almost immediately, should that become necessary to avert a climate emergency or to buy time to more fully implement mitigation.[30] For a rapid reduction in the amount of atmospheric carbon and its consequences, climate engineering is the only choice.

D. *The Risks Associated with Geoengineering Exceed Those of Other Responses to Climate Change*

Despite the advantages of climate engineering, these technologies also involve significant risks. Scientists recognize several potential risks, some that might produce global consequences, others that might be more regional in effect. For instance, aerosol methods relying upon sulfate particles might trigger acid rain, which harms fish, plant, and, indirectly, bird populations;[31] drops in global precipitation levels;[32] and depletion of the ozone layer.[33] Albedo modification may impair ecosystem productivity from reduced photosynthesis.[34]

2016), http://www.rollingstone.com/politics/news/will-the-paris-climate-deal-save-the-world-20160113; Michael Levi, Was the Paris Climate Deal a Success?, NEWSWEEK OPINION (Dec. 14, 2015), http://www.newsweek.com/was-paris-climate-deal-success-404715; John Sutter, *Hooray for the Paris Climate Agreement! Now What?*, CNN OPINION (Dec. 14, 2015), http://www.cnn.com/2015/12/14/opinions/sutter-cop21-climate-5-things/.

28 *See* William C.G. Burns, *Climate Geoengineering: Solar Radiation Management and its Implications for Intergenerational Equity*, 4 STAN. J. L., SCI. & POL'Y 37, 46 n.50 (2011). The related risk is that a rogue nation or group could decide unilaterally to engineer the climate. Barrett, *supra* note 24, at 46.

29 *See* Barrett, *supra* note 24, at 47.

30 *See* IPCC, *supra* note 17, at 96, 98.

31 *See* Ben Kravitz et al., *Sulfuric Acid Deposition from Stratospheric Geoengineering with Sulfate Aerosols*, J. GEOPHYSICAL RES. 1, 1 (2009). Sulfur is being considered in part because it is the element released by volcanoes, upon which this method is based. *See* Philip J. Rasch et al., *An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 4007, 4009 (2008).

32 *See* Bryan Walsh, *Can Geoengineering Help Slow Global Warming?*, TIME (Aug. 18, 2009), http://www.time.com/time/health/article/0,8599,1916965,00.html.

33 *See* Simone Tilmes et al., *Impact of Geoengineered Aerosols on the Troposphere and Stratosphere*, 114 J. GEOPHYSICAL RES. D12305, at 2 (2009).

34 *See* William Daniel Davis, *What Does "Green" Mean?: Anthropogenic*

Another potential consequence arising from SRM involves the "termination" effect.[35] Since SRM will merely provide a cooling effect without reducing the amount of carbon in the atmosphere,[36] the atmosphere is still subject to warming if we discontinue the SRM technology. Scientists calculate that, under such circumstances, the planet would warm rapidly upon a sudden cessation of SRM.[37] If an SRM technology is stopped abruptly, the resulting re-warming could occur up to 20 times faster than the current warming rate of 0.2°C per decade.[38] Because of the inability of natural systems to adapt to rapid change, "the rate of change of [the] climate . . . is more disruptive than the actual climate [level]."[39] In fact, scientists project that only 30 percent of all impacted ecosystems would be able to adapt at a warming rate of merely 0.3°C per decade.[40] Thus, because of carbon's long atmospheric lifetime, to avoid this termination effect, SRM techniques might need to be perpetuated for at least a millennium.[41]

In addition to these potential global consequences, climate engineering methods may also cause a number of localized effects. Since SRM will not reduce the atmospheric carbon level, the resulting atmosphere may be characterized by reduced levels of precipitation. Lower precipitation may particularly impact East and Southeast Asia, Africa, and the Amazon and Congo valleys. This could undermine the food security of two billion people.[42]

Climate Change, Geoengineering, And International Environmental Law, 43 GA. L. REV. 901, 924 (2009). Albedo involves "the fraction of solar radiation reflected by a surface or object." Bindoff, *supra* note 6, at 941. Thus, snow has a high albedo, while oceans and vegetation-covered surfaces have low albedos.

35 Burns, *supra* note 28, at 47 (stating that this effect results from the accumulation of greenhouse gases during the period that the SRM technology was applied).

36 *Id.* at 47.

37 *See* Victor Brovkin et al., *Geoengineering Climate by Stratospheric Sulfur Injections: Earth System Vulnerability to Technological Failure*, 92 CLIMATIC CHANGE 243, 253–54 (2009).

38 Burns, *supra* note 28, at 47.

39 Alan Robock, *Stratospheric Aerosol Geoengineering*, 38 ISSUES IN ENV'T SCI. & TECH. 162, 171–72 (2014).

40 Burns, *supra* note 28, at 48.

41 *See* Antti-Ilari Partanen et al., *Direct and Indirect Effects of Sea Spray Geoengineering and the Role of Injected Particle Size*, 117 J. GEOGRAPHICAL RES. D2203, 15 (2012) (citing Brovkin, *supra* note 37).

42 Burns, *supra* note 28, at 40.

Although many believe the risks of geoengineering are sufficient cause to reject it as a response to climate change,[43] a number of countries have already initiated climate engineering research.[44] Indeed, China, the largest greenhouse gas emitter,[45] has identified geoengineering among its earth science research priorities.[46] Similarly, India, another developing country investing heavily in coal power plants,[47] also is engaging in geoengineering research.[48] Russia not only supports geoengineering research,[49] it has actually conducted one of the first SRM field experiments.[50]

Maybe most importantly, we may feel a moral obligation to engineer the climate. Climate change will most significantly impact those populations least able to adapt,[51] and climate engineering may provide one of the few alternatives to minimize

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43 *See* Alan Robock, *20 Reasons Why Geoengineering May Be a Bad Idea*, 64 BULL. ATOMIC SCI. 14, 17–18 (2008) [hereinafter *20 Reasons*]. Another objection commonly raised, that geoengineering will create a moral hazard, is discussed more fully *infra* at Section III.C.

44 These nations include the United Kingdom, France, Germany, and Norway. Anthony E. Chavez, *A Napoleonic Approach to Climate Change: The Geoengineering Branch*, 5 WASH. & LEE J. CLIMATE & ENV'T 93, 123 (2014).

45 *See* Steven Mufson, *China's Pledge to Cut Greenhouse Gases Eliminates Excuse for Other Nations*, WASH. POST (Nov. 12, 2014), https://www.washingtonpost.com/business/economy/chinas-pledge-to-cut-greenhouse-gases-eliminates-excuse-for-other-nations/2014/11/12/5a22b0de-6a8f-11e4-a31c-77759fc1eacc_story.html.

46 Clive Hamilton, *Why Geoengineering Has Immediate Appeal to China*, THE GUARDIAN (Mar. 22, 2013), http://www.theguardian.com/environment/2013/mar/22/geoengineering-china-climate-change.

47 *See* Candace Dunn, *India Is Increasingly Dependent on Imported Fossil Fuels as Demand Continues to Rise*, U.S. E.I.A. (Aug. 14, 2014), http://www.eia.gov/todayinenergy/detail.cfm?id=17551 (noting that India is currently the third-largest global coal producer, consumer, and importer of coal, with demand increasing by seven % per year over the past five years).

48 *See* Christopher J. Preston, *Solar Radiation Management and Vulnerable Populations: The Moral Deficit and Its Prospects*, *in* ENGINEERING THE CLIMATE, THE ETHICS OF SOLAR RADIATION MANAGEMENT 82 (Christopher J. Preston ed., 2012).

49 Martin Lukacs et al., *Russia Urges UN Climate Report to Include Geoengineering*, THE GUARDIAN (Sep. 19, 2013), http://www.theguardian.com/environment/2013/sep/19/russia-un-climate-report-geoengineering.

50 Jeremy Hsu, *First Geoengineering Field Trial Carried Out in Russia*, POPULAR SCIENCE (Dec. 14, 2009), http://www.popsci.com/technology/article/2009-12/first-geoengineering-field-trial-carried-out-russia-0.

51 Scientists anticipate that the impacts of climate change will "fall largely and disproportionately on the developing world." Tiffany T.V. Duong, *When Islands Drown: The Plight of "Climate Change Refugees" and Recourse to International Human Rights Law*, 31 J. INT'L L. 1239, 1241 (2014).

this suffering.[52] The possibility that it could provide a meaningful reduction in climate risks for the most vulnerable persons and ecosystems[53] may render it too compelling to ignore.

For all of these reasons and others, the likelihood that climate engineering will be seriously considered is growing.[54] The point of this Article is not to advocate either way. Instead, it proposes a principled approach to evaluate whether to deploy particular geoengineering technologies.

II. SEVERAL LEGAL PRINCIPLES CAN GUIDE DECISIONS TO DEPLOY GEOENGINEERING TECHNOLOGIES

To determine how we should deploy geoengineering, we need to identify a set of principles with which to make such a decision. Legal doctrines and statutory approaches suggest several considerations which might be included. While they may not all be helpful or dispositive, they nevertheless can inform this process. By applying such principles, we can provide this determination with a principled basis and replicable structure.

The following legal principles may help guide the decision to deploy geoengineering:

A. *The Benefits of a Technology Should Outweigh Its Risks*

Three possible principles—the effectiveness of a remedy, cost-benefit analysis, and the precautionary principle—overlap. The first two consider the effectiveness of a solution, and the latter two weigh those benefits against its risks. Initially, this Article will review each separately. In Section III, it will consider how best to treat these overlapping principles.

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52 *See generally* Chris Caseldine, *So What Sort of Climate Do We Want? Thoughts on How to Decide What Is 'Natural' Climate*, 181 THE GEOGRAPHICAL J. 366, 367, 372 (2015).

53 *See* David Keith, *Climate Engineering, No Longer on the Fringe* (Feb. 18, 2015), HARV. JOHN A. PAULSON SCH. OF ENGINEERING AND APPLIED SCI., https://www.seas.harvard.edu/news/2015/02/climate-engineering-no-longer-on-fringe.

54 *See, e.g.*, NRC REPORT, supra note 1, at 5; Andy Ridgwell et al., *Geoengineering: Taking Control of Our Planet's Climate?*, 370 PHIL. TRANSACTIONS ROYAL SOC'Y A 4163, 4163 (2012) ("Concerns about the likely consequences of continuing climate change have greatly increased interest in geoengineering.").

1. *The technology should provide an effective remedy*

A remedy should be effective—it should leave a party better off than it would have been without the remedy.[55] Ideally, the remedy will restore the prior circumstance.[56] While courts will not accept wholly ineffectual remedies,[57] they also will not require a perfect remedy. Courts accept imperfect remedies, and they will even order remedies that they know will be imperfect.[58] Indeed, under certain circumstances, a court will sacrifice remedial effectiveness for other considerations. Specifically, it will balance the net benefits against the net societal costs.[59]

2. *The benefits of a technology should outweigh its risks*

The balancing of consequences through cost-benefit analysis is a strategy employed by policymakers to determine whether the implementation of a technology will be outweighed by its negative consequences. To best understand cost-benefit analysis, we need to consider comparative risk analysis, from which cost-benefit analysis derives. Under comparative risk analysis, if the comparative risks of an action are low, then the decision maker will readily select it.[60] If associated risks are high, then the decision maker should weigh the consequences thoroughly.[61]

Since 1990, environmental policymakers have widely used comparative risk analysis to assess the risk of implementing new technology impacting the environment.[62] Comparative risk analysis blends three principles. First, sound environmental policy

55 *See* Richard H. Fallon, Jr., *The Linkage between Justiciability and Remedies—And Their Connections to Substantive Rights*, 92 VA. L. REV. 633, 652 (2006).

56 *See* Sonja B. Starr, *Rethinking "Effective Remedies": Remedial Deterrence in International Courts*, 83 N.Y.U. L. REV. 693, 702 (2008) (noting that part of reparations for the violation of an international human right involves the restoration of the prior situation).

57 *See id.*

58 *See* Paul Gewirtz, *Remedies and Resistance*, 92 YALE L.J. 585, 590–91 (1983).

59 *See id.* at 591.

60 *See* Matthew L. Beran, *The Proportionality Balancing Test Revisited: How Counterinsurgency Changes "Military Advantage"*, ARMY L., Aug. 2010, at 4.

61 *Id.* at 3.

62 *See* Donald T. Hornstein, *Reclaiming Environmental Law: A Normative Critique of Comparative Analysis*, 92 COLUM. L. REV. 562, 563 (1992).

making should be analytic, not political.[63] Second, environmental risk should consider expected losses, such as the anticipated loss of habitat and ecosystems.[64] Third, the different risks should be reduced to a common metric.[65] The risk analysis must be standardized in quantitative terms and be uniform; different meanings of particular risks should be avoided.[66]

An important consideration when weighing future alternatives is valuation. Cost-benefit analysis typically discounts future costs and benefits to their present value.[67] Discounting, however, creates specific problems when applied to environmental issues. First, since discounting typically weighs present cost against future benefits, it usually produces a preference for current action—with a high present value—over deferred benefits—often substantially discounted over time.[68] Second, and more distressing, discounting may suggest that the health, indeed, the lives, of present persons are more valuable than those of future generations.[69]

63 *Id.* at 585.

64 *Id.*

65 *Id.*

66 Some SRM scientists have essentially supported a balancing approach. Keith and MacMartin considered the usefulness of a Pareto-optimal analysis. *See* David W. Keith & Douglas G. MacMartin, *A Temporary, Moderate, and Responsive Scenario for Solar Geoengineering* (Feb. 18, 2014), http://www.cds.caltech.edu/~macmardg/pubs/Keith-MacMartin-Scenario.pdf. They concluded that, with SRM deployment, some regions may always be worse off with heightened use of SRM, thus suggesting that the Pareto-improving amount of SRM would be zero. Recognizing that nearly every policy decision will make some people worse off, they concluded that approaches that fall between global and Pareto-optimality serve as better guides to policy. *See id.* at 5. In other words, the best approach would balance the tradeoffs between these points.

67 *See* Jeffrey M. Gaba, *Environmental Ethics and Our Moral Relationship to Future Generations: Future Rights and Present Virtue*, 24 COLUM. J. ENVTL. L. 249, 269 (1999).

68 *Id.*

69 *Id.* Indeed, a classic example of the impact of these assumptions has arisen concerning the costs of climate change mitigation. In 2006, the Stern Review on the Economics of Climate Change calculated the effect that climate change would have on global gross domestic product. The report concluded that the overall costs would be a loss of at least 5 percent of GDP and possibly as high as 20 percent. William D. Nordhaus, *A Review of the Stern Review on the Economics of Climate Change*, XLV J. ECON. LITERATURE 686, 687 (2007). However, the Stern Review reached this conclusion by applying a very low discount rate, which treats future generations equally with present generations. *Id.* at 689–90. Nordhaus severely criticized using this extremely low discount rate, labeling Stern Review's results as "bizarre" because it trades off a large fraction of today's income to increase a far-future income stream by a very tiny

As long as the potential benefits outweigh the potential losses, decision makers should treat these losses as acceptable.[70] Decision makers should consider the potential for excessive losses before deciding to implement a particular technology.[71] Where a consequence is inconceivably large and the benefit is limited, decision makers should decide against implementing that action. Thus, this principle would reject a new technology that likely will have excessive consequences harmful to the environment.[72]

3. *Precaution should guide decisions where scientific uncertainty suggests risk*

Parents caution their children to be "better safe than sorry." This simple advice summarizes the underlying theme of the precautionary principle.[73] The precautionary principle applies to activities with potential but unascertained risks of serious or irreparable harm. When an activity presents such a risk, the precautionary principle dictates postponement of the activity until more information about the risk is gathered.[74] As discussed in more depth below,[75] variations of the precautionary principle fall generally into one of two categories, "strong" and "weak."[76] These versions of the precautionary principle differ primarily in the manner they address decision-making in the face of uncertain risk.

Regarding environmental policy, the precautionary principle promotes placing a higher value on human health and environmental integrity over activities and technological advances

fraction. *Id.* at 696. This dispute over the appropriate discount rate demonstrates that decisions regarding discount rates can favor present or future generations. To the extent this result implicates an intergenerational conflict, this is addressed *infra* at Section III.D.

70 Decision makers also need to consider incidental repercussions, which arise when the resulting consequences are significant, but small enough that the benefits still outweigh the losses. *See* Beran, *supra* note 60, at 3.

71 *Id.*

72 *Id.*

73 *See* Kenneth L. Mossman & Gary E. Marchant, *The Precautionary Principle and Radiation Protection*, 13 RISK: HEALTH, SAFETY & ENV'T 137, 137 (2002).

74 *See* Frank B. Cross, *Paradoxical Perils of the Precautionary Principle,* 53 WASH. & LEE L. REV. 851, 851 (1996).

75 *See infra* notes 91–101 and accompanying text.

76 Alan Patterson & Tim Gray, *Unprincipled? The British Government's Pragmatic Approach to the Precautionary Principle*, 21 ENVTL. POL. 432, 437 (2012).

carrying potential risks of serious or irreparable harm.[77] The precautionary principle applies well to environmental policy considerations because the issues typically involve complex questions that scientific studies have not fully resolved.[78] In a sense, the precautionary principle encourages those making decisions to err on the side of caution when considering actions where the potential adverse effects on human health and the environment are unknown.[79]

The precautionary principle first appeared in 1969 in the Swedish Environmental Protection Act, which required parties to "demonstrate the safety of environmentally hazardous activities."[80] Since its inception,[81] the precautionary principle has become one of the foundational bases guiding health and environmental policy decisions in multiple countries as well as the European Union.[82] Despite this early and successful formulation, the seminal articulation of the precautionary principle came from the 1992 United Nations Rio Declaration on Environment and Development. It provides that where threats of serious and irreversible damage may arise, "lack of full scientific certainty

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77 *See* John S. Applegate, *The Taming of the Precautionary Principle*, 27 WM. & MARY ENVTL. L. & POL'Y REV. 13, 13 (2002) ("At its core, the precautionary principle embodies two fundamental regulatory policies: anthropogenic harm to human health and the environment should be avoided or minimized through anticipatory, preventive regulatory controls; and, to accomplish this, activities and technologies whose environmental consequences are uncertain but potentially serious should be restricted until the uncertainty is largely resolved.").

78 *See* Joel Tickner & David Kriebel, *The Role of Science and Precaution in Environmental and Public Health Policy*, *in* IMPLEMENTING THE PRECAUTIONARY PRINCIPLE: PERSPECTIVES & PROSPECTS 42 (Fisher et al. eds., 2006).

79 *See* Patterson & Gray, *supra* note 76, at 436.

80 Ragnar E. Löfstedt, Baruch Fischhoff & Ilya R. Fischhoff, *Precautionary Principlés: General Definitions and Specific Applications to Genetically Modified Organisms*, 21 J. POL'Y ANALYSIS & MGMT. 381, 382 (2002).

81 Soon thereafter, the precautionary principle started appearing in German environmental policies, most notably in its 1974 Clean Air Act. *See id.* at 382–83.

82 *See* Patterson & Gray, *supra* note 76, at 43 ("Britain is bound by numerous European Union (EU) directives and regulations which inscribe the PP in its environmental and health policy-making, and as far back as 1990, the government acknowledged precaution as one of five principles to guide its policies on the environment . . . ."). Other international unions and non-European countries have followed suit, implementing the precautionary principle or some version of it into their policy-making framework. *See* Mossman & Marchant, *supra* note 73, at 138.

shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[83] Although this version of the precautionary principle appears frequently, it does not paint a complete picture of the principle's complexity. Its application across multiple states and international unions has led to multiple interpretations of the precautionary principle and disagreements over its application in environmental policies.[84]

Another variation of the precautionary principle comes from the Wingspread Declaration, which derives from a 1998 meeting of environmentalists.[85] This version provides that precautionary measures should be taken when an activity threatens human health or the environment, "even if some cause-and-effect relationships are not established scientifically."[86] It places the burden of proof on the proponent of the activity, rather than its critic.[87] Although this iteration of the principle is similar to the 1992 Rio Declaration version, the differences between them have proven a divisive subject in environmental policy discussion.

The strong precautionary principle does not allow any room for additional considerations regarding the risk of serious harm. It rejects any activity or technology unless scientific evidence proves it does not harm the environment.[88] The strong precautionary principle places the responsibility of proving an activity safe or reasonable on the party advocating it, making precaution—prohibiting the activity—the default action.[89] Unlike the weak precautionary principle, the strong principle considers neither the degree of risk involved, nor the cost of making an activity safe. Instead, it asks whether a party can prove beyond reasonable scientific doubt that an activity is in fact safe for the

83 Mossman & Marchant, *supra* note 73, at 138 (quoting Rio Declaration on Environment and Development, June 13, 1992, 31 I.L.M. 874).

84 *See id.* at 138–39.

85 Harry Boyte & Elizabeth Hollander, *Wingspread Declaration on the Civic Responsibilitites of Research Universities*, CAMPUS COMPACT, http://compact.org/wingspread-declaration-on-the-civic-responsibilities-of-research-universities (last visited Jan. 20, 2016) (containing a link to a pdf version of the declaration as it was originally printed in June 1999).

86 Cass R. Sunstein, *Beyond the Precautionary Principle*, 151 U. PA. L. REV. 1003, 1006 (2003).

87 *See* Patterson & Gray, *supra* note 76, at 437.

88 *See id.*

89 *See* Sunstein, *supra* note 86, at 1012–13.

environment.[90] Conservationists and environmental organizations favor this approach because it places the burden on potential actors to prove their activities are not harmful to the environment.[91]

Conversely, critics of the strong precautionary principle argue that it is too vague and offers no pragmatic guidance on how to accomplish its directives.[92] In addition, the exercise of excessive precaution may, in certain cases, inadvertently cause more harm than good. For example, consider the case of a substance that is toxic at higher levels but beneficial in smaller quantities. The strong precautionary principle, evidenced through a complete ban on the substance, may cause harm by preventing its beneficial applications.[93]

The "weak" version is less stringent in determining how much precaution one should take.[94] Under the "weak" version of the precautionary principle, decisions regarding whether to continue or halt an activity are not made solely on whether a potential risk exists. The "weak" version also considers other factors, such as cost effectiveness. The 1992 Rio Declaration provides an example of this model.[95]

The effect of this type of approach to the precautionary principle is that it no longer functions as a guiding principle. The weak precautionary principle functions more as a balancing system that "allows evidence of negative socio-economic costs to be weighed against the positive environmental benefits of banning a harmful development."[96] The principle becomes a risk-management approach regarding potential risks of harm. Instead of

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90 *See* Noah M. Sachs, *Rescuing the Precautionary Principle from Its Critics*, 2011 U. ILL. L. REV. 1285, 1295 (2011).

91 *See* Patterson & Gray, *supra* note 76, at 437 ("Here the onus is placed on the polluters to prove *beyond all doubt* that his/her polluting activities will not damage the environment: that is, there has to be *certainty* that no harm will befall the environment if no intervention is made.") (emphasis in original).

92 *See* Sunstein, *supra* note 86, at 1020.

93 *Id.* at 1026–27.

94 Sachs, *supra* note 90, at 1295.

95 *See* Sunstein, *supra* note 86, at 1012; *see also* Sachs, *supra* note 90, at 1292–93 ("'Weak' versions of the Precautionary Principle stand for the proposition that regulators should be empowered to address risk in contexts of scientific uncertainty—that is, even before regulators fully understand the nature or extent of risk. One widely cited 'weak' version of the Precautionary Principle is contained in the Rio Declaration, adopted by consensus by 172 countries (including the United States) at the Earth Summit in 1992.").

96 Patterson & Gray, *supra* note 76, at 437.

erring on the side of caution and discontinuing an activity, the decision maker considers the degree of the threat with the potential benefits of the activity and the possible results from its postponement.[97] Critics of the weak precautionary principle argue that this balancing approach undermines the entire purpose of the precautionary principle altogether, which is to place the prevention of serious or irreparable harm above all else.[98]

B. *We Should Consider Alternatives to Proposed Actions*

Before deciding whether to implement a new technology, decision makers often establish a framework identifying the available alternatives and developing for each a quantifiable measurement, explanation, and description.[99] Most people believe that actors can be blamed or praised for their actions only if they have the ability to choose to act differently; philosophers call this the principle of alternate possibilities.[100] The principle of alternate possibilities states that before undertaking a certain action, a decision maker must consider alternative courses. This principle gives policymakers the flexibility to choose effectively among the various options.[101] When multiple possible outcomes for a given action exist, policymakers must balance the options and select the most beneficial one.

The National Environmental Policy Act (NEPA) provides an example of this approach. The explicit purpose of NEPA is to "insure that environmental information is available to public officials and citizens before decisions are made and before actions are taken."[102] Through its requirement of an environmental impact statement (EIS), NEPA ensures that decision makers consider alternatives to their proposed action.[103] Emphasizing alternatives is central to the decision-making process,[104] and NEPA requires the

97 *Id.*

98 *Id.*

99 *See, e.g.*, 1 FRANK B. CROSS, FEDERAL ENVIRONMENTAL REGULATION OF REAL ESTATE § 1:8, Westlaw (database updated Sept. 2015).

100 *See* Luis E. Chisea, *Punishing Without Free Will*, 2011 UTAH L. REV. 1403, 1422–23 (2011).

101 *Id.* at 1403.

102 40 C.F.R. §1500.1(b) (2015).

103 40 C.F.R. §1508.25(b) (2015).

104 Indeed, the consideration of alternatives is considered to be the "heart" of the NEPA process. 40 C.F.R. §1502.14 (2015).

presentation of alternatives to be in comparative form.[105] The comparison should sharply define the issues and provide a clear basis for choosing among the options.[106] The consideration of alternatives should include all reasonable courses of action and, for comparison, the no-action alternative.[107]

When considering the adequacy of alternatives under NEPA, courts apply a standard of reasonableness.[108] Reasonableness is met when the EIS presents various alternatives, including the purpose and need for each alternative.[109] The EIS must "rigorously explore and objectively evaluate all reasonable alternatives," and, if the agency eliminates any alternative from detailed study, the agency must briefly discuss in the EIS why that alternative was not considered with the others.[110] Therefore, an agency may eliminate an alternative from consideration because it is unreasonable.[111] For example, alternatives which inadequately address the proposal's need and purpose can also be considered unreasonable.

As NEPA demonstrates, the consideration of alternatives provides several benefits. First, it assures that the decision makers have considered methods of achieving the desired goal other than the proposed action.[112] Second, it assures that decision makers do not act on incomplete information, or overlook or understate important effects.[113] Third, it better guarantees that the decision makers seriously consider the environmental effects of reasonable and realistic courses of action.[114] Finally, it fosters informed public

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105 *See* James Allen, *NEPA Alternatives Analysis: The Evolving Exclusion of Remote and Speculative Alternatives*, 25 J. LAND RESOURCES & ENVTL. L. 287, 294 (2005).

106 *Id.* at 294.

107 40 C.F.R. §1502.14.

108 *See, e.g.*, Associated Fisheries of Maine,Inc. v. Daley, 127 F.3d 104, 114 (1st Cir. 1997).

109 40 C.F.R. § 1502.14(a).

110 RAY VAUGHAN, 38 AMERICAN JURISPRUDENCE PROOF OF FACTS § 6 (3d ed. 1992).

111 *See* Allen, *supra* note 105, at 295.

112 *See* Ass'n Concerned About Tomorrow, Inc. v. Slater, 40 F.Supp.2d 823, 832 (N.D. Tex. 1998).

113 *See* Am. Canoe Ass'n v. White, 277 F. Supp. 2d 1244, 1250 (N.D. Ala. 2003). Identifying alternatives demonstrates that the decision makers have considered other approaches. *See* Sierra Club v. Morton, 510 F.2d 813, 825 (5th Cir. 1975).

114 *See* Dep't of Transp. v. Blue, 147 N.C. App. 596, 604 (2001).

engagement.[115]

C. We Should Avoid Creating a Moral Hazard

Moral hazard is an economic concept. A moral hazard arises when one party party consents to accept some of the potential negative consequences of other parties' actions, and one or more of these other parties then increase the riskiness of their behavior.[116] This concept most clearly arises in the context of insurance.[117] One commentator has even referred to the moral hazard problem as "taking advantage" of insurance.[118] In this context, a moral hazard arises when insured persons engage in riskier behavior than they would without insurance, since they are insulated from the costs of their behavior.[119] Researchers have found examples of this behavior in an array of insurance contexts, including health insurance,[120] workers' compensation,[121] automobile insurance,[122] and even flood insurance.[123] They have also identified non-insurance contexts, ranging from the perpetration of genocide[124] to bailouts of financial institutions,[125]

115 *See* Resources Ltd., Inc. v. Robertson, 35 F.3d 1300, 1306 (9th Cir. 1993). By providing informing regarding alternatives, the decision makers provide members of the public with information that they can evaluate and balance on their own. *Sierra Club*, 510 F.2d at 825.

116 Jesse Reynolds, *A Critical Examination of the Climate Engineering Moral Hazard and Risk Compensation Concern*, 2 ANTHROPOCENE REV. 174, 176 (2015).

117 Stephen M. Gardiner, *Some Early Ethics of Geoengineering the Climate: A Commentary on the Values of the Royal Society Report*, 20 ENV'T VALUES 163, 166 (2011).

118 Ben Hale, *The World That Would Have Been: Moral Hazard Arguments Against Geoengineering*, *in* ENGINEERING THE CLIMATE: THE ETHICS OF SOLAR RADIATION MANAGEMENT, *supra* note 48, at 116.

119 Gardiner, *supra* note 117, at 166.

120 Albert C. Lin, *Does Geoengineering Present a Moral Hazard?*, 40 ECOLOGY L.Q. 673, 686 (2013) (finding that health insurance coverage leads to increased demand for medical care and that the insured tend to increase unhealthy behaviors).

121 *Id.* (finding that increases in worker-compensation benefits correlate with increases in both the duration of claims and the reporting of accidents).

122 *Id.* at 687 (finding positive relationship between traffic fatalities and insurance coverage).

123 *Id.* (finding increase in development in flood-prone areas in areas covered by the National Flood Insurance Program).

124 *Id.* (finding that humanitarian intervention to protect vulnerable groups against state-perpetrated genocide fosters expectations of future intervention, leading rebel groups to take risks that they otherwise would not have taken).

as involving similar concerns.

Despite the frequent raising of moral hazard as an objection to geoengineering, the concept's fit is less than perfect. A moral hazard contemplates the existence of two parties with diverging interests.[126] Specifically, one party *consensually* accepts risk transferred from the other party.[127] Geoengineering, on the other hand, involves multiple parties (all of human society) spread over time (multiple generations), with no opportunity to consent.[128]

Consequently, a concept related to moral hazard that may apply better to this context is risk compensation. This theory predicts that measures designed to reduce risk actually prompt more risky behaviors because affected parties choose to maintain their same level of risk.[129] Examples of this shift in behavior occur when people use seatbelts,[130] protective sports equipment, condoms, and hypertension drugs.[131] Several factors can influence risk compensation behavior. They include "the visibility of the safety measure, the extent to which the measure affect one's perception of risk, the motivations underlying individual behavior,

125 *Id.* at 688 (finding that expectations of financial bailouts encouraged excessive risk taking). Other examples include mutual defense treaties, foreign aid, humanitarian intervention, and financial investments. Reynolds, *supra* note 116, at 4.

126 Lin, *supra* note 120, at 688.

127 Reynolds, *supra* note 116, at 5.

128 *Id.* To the extent that geoengineering pits the interests of the current generation against those of future generations, this conflict should be analyzed as a problem of intergenerational justice, not of moral hazard *see infra* Section III.D. A moral hazard arises when one party *assumes* a risk, thereby enabling a second party to engage in riskier behavior. Reynolds, *supra* note 116, at 3. In the present context, this would be comparable to the present generation assuming a risk that enables subsequent generations to engage in risky behavior (here, emitting greenhouse gases). Critics charging that geoengineering could give rise to a moral hazard argue that it enables the *current* generation to continue emitting greenhouse gases by shifting the burden of addressing the consequences of those emissions to subsequent generations. *See* Davis, *supra* note 34, at 946–47 (recognizing that geoengineering will reduce the current political will to adopt mitigation policies to reduce GHG emissions). However, such a transfer is not a moral hazard because future generations have no opportunity to consent to the assumption of risk.

129 *See generally* Lin, *supra* note 120, at 689.

130 Reynolds, *supra* note 116, at 4 (noting that early studies showing seat belt using leading to more dangerous driving, though more recent studies found a less significant connection).

131 *Id.*

and one's ability to control risk."[132]

D. *We Should Minimize Harm to Future Generations*

The concept of intergenerational equity recognizes the entitlement of each generation to a planet comparable to that available to the previous generation.[133] It seeks to ensure a minimum planetary resource base for each generation as enjoyed by its ancestors.[134] From an alternative perspective, it preserves the largest possible range of options for future generations, thereby protecting their freedom of choice.[135] Intergenerational justice also addresses the sharing of harms and benefits across generations.[136] It is similar in concept to notions of trusteeship, stewardship, and tenancy, which require the conservation of assets so they are available for future groups.[137] "Future generations," as used in this principle, is usually understood broadly so as to include all unborn persons into the future, without limitation.[138] Furthermore, intergenerational equity recognizes an obligation to future generations regardless of the specific preferences, or even the identities, of these future individuals.[139]

Environmental proscriptions have incorporated intergenerational concerns since the 1970's. The 1972 Stockholm Declaration Preamble, for instance, identifies a goal of defending and improving the environment for "present and future generations."[140] Additional contemporaneous expressions of

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132 Lin, *supra* note 120, at 690.

133 *See* Edith Brown Weiss, *Our Rights and Obligations to Future Generations for the Environment*, 84 AM. J. INT'L L. 198, 200 (1990).

134 *Id.* at 200.

135 *See* Holly Doremus, *The Rhetoric and Reality of Nature Protection: Toward a New Discourse*, 57 WASH. & LEE L. REV. 11, 71–72 (2000).

136 Toby Svoboda et al, *Sulfate Aerosol Geoengineering: The Question of Justice*, 25 PUBLIC AFFAIRS Q. 157, 174 (2011). Svoboda notes an interrelationship between intergenerational and distributive justice. Specifically, present persons should not compromise the distributive justice of future generations. *Id.* at 20.

137 *Id.*

138 Burns H. Weston, *Climate Change and Intergenerational Justice: Foundational Reflections*, 9 VT. J. ENVTL. L. 375, 383–84 (2008).

139 *See* Bradford C. Mank, *Protecting the Environment for Future Generations: A Proposal for a "Republican" Superagency*, 5 N.Y.U. ENVTL. L.J. 444, 448–49 (1996).

140 United Nations Conference on the Human Environment, Declaration of the United Nations Conference on the Human Environment, June 16, 1972, 11 I.L.M. 1416.

concern for future generations were included in the 1972 London Ocean Dumping Convention, the 1972 World Cultural and Natural Heritage Convention, the 1973 Endangered Species Convention, and the 1974 Charter of Economic Rights and Duties of States.[141] The 1987 report of the U.N. World Commission on Environment and Development (WCED) defined this interest more specifically. The WCED proclaimed that for socioeconomic development to be sustainable, it must meet "the needs of the present without compromising the ability of future generations to meet their own needs."[142]

Domestic environmental laws similarly began to incorporate intergenerational concerns. For instance, the 1970 National Environmental Policy Act calls upon the Federal Government to use all practicable means so that the Nation may "fulfill the responsibilities of each generation as trustee of the environment for succeeding generations."[143] Similarly, the Wild and Scenic Rivers Act protects certain selected rivers "for the benefit and enjoyment of present and future generations."[144]

E. *We Should Avoid Disparate Regional Impacts*

A related concern involves avoiding regional inequities. An unequal distribution might violate notions of distributive, or intragenerational, justice. Distributive justice concerns the sharing of harms and benefits among persons.[145] In the present context, the concern might arise not because of the distribution of harms among different individuals, but from harms imposed upon different groups of individuals, or more precisely, different regions of the world.[146]

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141 Weston, *supra* note 138, at 389–90 (noting that in each of these conventions and charters, "identical concern for the ecological legacy we leave to future generations was formally expressed.").

142 *Id.* at 390.

143 42 U.S.C.A. § 4331(b)(1) (2012).

144 16 U.S.C.A. § 1271 (2012).

145 *See* Svoboda, *supra* note 136, at 164.

146 Similar but distinct principles would reach comparable results. The first such principle concerns protection of vulnerable populations, especially those with reduced abilities to protect themselves. *See* Pablo Suarez, Jason Blackstock & Maarten van Aalst, *Towards a People-Centered Framework for Geoengineering Governance: A Humanitarian Perspective*, GEONGINEERING Q., Mar. 20, 2010, at 3, http://www.greenpeace.to/publications/The_Geoengineering_Quarterly-First_Edition-20_March_2010.pdf. Another dichotomy that commentators have identified arises between wealthy and poor nations. *Id.* These

While a number of egalitarian theorists have addressed distributive justice and the sharing of harms and benefits, perhaps the theories most on point are those of John Rawls. Rawls believes that two principles of justice should control. First, each person has an equal right to basic liberties; second, social inequalities should "be to everyone's advantage" and be attached to positions open to all.[147] Thus, Rawls would allow an unequal distribution of harms and benefits if this inequality benefits everyone, so long as it does not compromise persons' basic liberties and opportunities.[148] Although this theory could be understood to allow the unequal distribution of climate engineering harms, any compromise basic liberties and opportunities of groups might violate this proscription.

Another conceptualization of distributive justice comes from Amartya Sen. Sen views the most important benefits as the basic capabilities that allow one to pursue the activities that one values; the most significant harms are the absence of such capabilities.[149] Among a person's basic capabilities are the ability to meet one's nutritional, clothing, and shelter requirements.[150] Thus, actions that impair groups' ability to secure these necessities give rise to unjust distributions.

F. *We Should Seek to Preserve the Natural State of the Environment*

Humans recognize an inherent value and dignity to the natural environment.[151] We appreciate the state of nature untouched by man's influence. Even more, we value the natural evolution of the environment and of species, absence manipulation by man to achieve a particular result dictated by humans.

Natural resources law and policy largely derives from concerns of preservation and restoration of ecological systems to

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distinctions, while meaningful, are less clear. More importantly, in this context, any disparate consequences stem less from those underlying differences than from the geographic location of the populations involved.

147 Svoboda, *supra* note 136, at 165.

148 *Id.* at 166.

149 *Id.*

150 *Id.* at 163.

151 *See* Mark Sagoff, *We Have Met the Enemy and He Is Us or Conflict and Contradiction in Environmental Law*, 12 ENVTL. L. 283, 307–08 (1982).

pristine states.[152] This principle underlies the 1964 Wilderness Act.[153] The Act identifies wilderness as an area "untrammeled by man" that "retain[s] its primeval character and influence, without permanent improvements."[154] It also recognizes an intrinsic value to the preservation of the wild character of certain lands.[155] Furthermore, maintaining the natural environment free of technological interference enables us to better understand the coexistence of species both among one another and with the environment.[156] The natural state is also important because it best preserves biodiversity.[157]

At least one court has recognized this priority of the natural state. Nearly half a century ago, a property owner challenged a shoreline zoning ordinance that prohibited his filling of wetlands areas.[158] The Wisconsin Supreme Court held that the owner had "no absolute and unlimited right to change the essential natural character of his land so as to use it for a purpose for which it was unsuited in its natural state."[159]

Intergenerational equity[160] also supports preserving nature. Humans have an interest in conferring to subsequent generations a planet comparable to the one into which they were born. The natural environment thus serves as a benchmark for future generations.[161]

A utilitarian perspective also supports preserving the natural state. Naturally functioning ecosystems provide a number of ecosystem services.[162] Ecosystem services include "timber

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152 *See* Alejandro E. Camacho, *Transforming the Means and Ends of Natural Resources Management*, 89 N.C. L. REV. 1405, 1426 (2011).

153 Wilderness Act, 16 U.S.C. §§ 1131–36 (1964).

154 Olivia Brumfield, *The Birth, Death, and Afterlife of the Wild Lands Policy: The Evolution of the Bureau of Land Management's Authority*, 44 ENVTL. L. 249, 255 (2014).

155 *See* Camacho, *supra* note 152, at 1427.

156 *See* SCOTT R. SANDERS, A CONSERVATIONIST MANIFESTO 7 (2009).

157 *See* Christopher C. Joyner, *Biodiversity in the Marine Environment: Resource Implications for the Law of the Sea*, 28 VAND. J. TRANSNAT'L L. 635, 649 (1995).

158 Just v. Marinette Cty., 201 N.W.2d 761, 766–67 (1972).

159 *Id.* at 768.

160 Discussed more fully *supra* at Section III.D.

161 *Just*, 201 N.W.2d at 768 (recognizing the state's duty to eradicate pollution, thereby returning the environment to its "natural *status quo*").

162 Jerry Melillo & Osvaldo Sala, *Ecosystem Services*, *in* SUSTAINING LIFE: HOW HUMANS DEPEND ON BIODIVERSITY 75, 75 (Eric Chivian & Aaron

production, water supply," water purification, and maintenance of air quality.[163] Natural ecosystems also generate and maintain biodiversity. Biodiversity provides genetic resources critical to industries such as agriculture and medicine.[164] Without ecosystems, "humans would be left to attempt to provide these services by themselves."[165]

Humans, of course, are not the only species that modifies the environment. The example often cited is that of beavers damming rivers.[166] Modifications initiated by humans, however, have been of a different nature and scale from those caused by other species. Humans "exert a disproportionate influence" on a natural system, acting not as a part of nature but outside it.[167] In such circumstances, the changes imposed upon nature do not result from a series of species or system interactions, but, instead, result solely from the acts of a single species.[168] Furthermore, the acts of humans, unlike those of other species, can dramatically impact ecosystems and cause widespread destruction.[169]

Preservation of the natural state especially arises as a concern in the context of industrial and post-industrial technologies. The combination of a globalized economy and exponential advances in technological capacity enable the disruption of nature on a global scale.[170]

G. *We Should Avoid Irreversible Consequences*

Irreversibility of harm is a significant consideration in

Bernstein eds., 2008).

163 Rachelle Adam, *Missing the 2010 Biodiversity Target: A Wake Up Call For the Convention of Biodiversity?*, 21 COLO. J. INT'L ENVTL. L. POL'Y 123, 133 (2010).

164 *See* Matthew D. Bockey, *To Keep Every Cog and Wheel: Preserving Biodiversity Through the Endangered Species Act's Protection of Ecosystems*, 41 CAP. U. L. REV. 133, 164 (2013).

165 *Id.* at 167.

166 *See* Marc Ereshefsky, *Where the Wild Things Are: Environmental Preservation and Human Nature*, 22 BIOLOGY & PHIL. 57, 62 (2007).

167 Bruce Pardy, *Changing Nature: The Myth of the Inevitability of Ecosystem Management*, 20 PACE ENVTL. L. REV. 675, 685 (2003).

168 *Id.*

169 *See* Ereshefsky, *supra* note 166.

170 *See* Adam Corner, et al., *Messing with Nature? Exploring Public Perceptions of Geoengineering in the UK*, GLOBAL ENVTL. CHANGE, Oct. 2013, at 938, 940. Geoengineering even more squarely confronts these concerns, since it presents the prospect that humans will shape, manage, and control nature. *Id.*

evaluating possible environmental damage and its prevention. Harm is irreversible "when restoration of the status quo is impossible or at best extremely difficult, at least on a relevant timescale."[171] Decision makers should avoid actions that may yield consequences that are irreversible and extreme.[172] Irreversible consequences justify a special degree of caution.[173] This principle is especially appropriate in the context of climate change, since irreversibility is an important consideration of all aspects of climate change.[174]

While the concept seems simple, its application can be more difficult. Actions may have irreversible consequences in one timeframe, but not in others.[175] For instance, trees lost through deforestation can eventually regrow. Similarly, most environmental destruction can be cured, but only after investments of extensive time and effort.[176] On the other hand, other actions unquestionably cannot be undone. Most species extinctions would fall into this category. Finally, irreversibility should also include an element of seriousness or magnitude.[177]

Irreversibility also can play a role in the application of the precautionary principle. Several applications of the principle require the utilization of precautionary actions upon threat of "irreversible damage."[178]

H. *We Should Be Able to Contain the Effects of a Technology*

An important consideration is whether the consequences of a

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171 Cass Sunstein, *Irreversible and Catastrophic,* 91 CORNELL L. REV. 841, 860 (2006).

172 *See generally* Nathan Ostrander, *A Warning Signal That Justifies Precautionary Chemical Regulation: Exploitation of the Availability Heuristic by Economically Motivated Actors,* 18 BUFF. ENVTL. L.J. 199, 218 (2011).

173 *See* Evan Jensen, *Banning Neonicotinoids: Ban First, Ask Questions Later,* 5 SEATTLE J. ENVTL. L. 47, 65 (2015).

174 *See* H. Holger Rogner et al., *Introduction, in* CLIMATE CHANGE 2007: MITIGATION: CONTRIBUTION OF WORKING GROUP III TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 102 (Metz et al. eds., 2007).

175 *Id.*

176 *Cf.* Sunstein, *supra* note 171, at 862 (characterizing environmental damage in some instances, including deforestation, as irreversible where it is serious, extremely expensive, and time consuming to reverse).

177 *Id.* at 861. Thus, for example, the loss of an "extremely small forest, with little wildlife" would not suffice, even if it were irreversible. *Id.*

178 *Id.* at 843–44.

technology can be limited to their intended range. Since we may not always be able to foresee a technology's consequences, we need to reduce the risk that they can escape to an unanticipated location and cause unforeseen consequences.

One example of the problems of containability and the consequences of breaking containment comes from biotechnology. New biotechnologies introduce organisms into specific environments, but these organisms often relocate to non-native locations through cross-pollination, wind, and insects.[179] Once these organisms enter new environments, they tend to reproduce rapidly and invade the environment, thus becoming invasive species.[180] These invasive species can alter the biodiversity of the environment through predation[181] and hybridization, which, in this context, may occur when a genetically-engineered species cross-breeds with a native species.[182] Through either mechanism, invasive species can diminish biodiversity in the environment by eliminating native species.[183]

Where containability concerns arise, regulatory bodies will impose special requirements to minimize environmental risks. Two particularly informative examples derive from NASA and from the Office of Science and Technology Policy (OSTP). NASA has emphasized the need to understand the risks and consequences of the escape of foreign material. Prevention of contamination requires a thorough understanding of what constitutes contamination and the harmful effects to environments experiencing contamination.[184] Before implementing a contamination control procedure, policymakers need to determine the types of potential contaminants, how they form and spread, and

179 Jonathan M. Jeschke, Felicia Keesing & Richard S. Ostfeld, *Novel Organisms: Comparing Invasive Species, GMOs, and Emerging Pathogens*, 42 AMBIO 541, 544 (2013).

180 *Id.* at 542.

181 *Id.* at 546 (recognizing that invasive species may act as predators in their new environments).

182 *See* Clint C. Muhlfeld et al., *Invasive Hybridization in a Threatened Species Is Accelerated by Climate Change,* 4 NATURE CLIMATE CHANGE 620, 620–24 (2014).

183 Jeschke et al., *supra* note 179, at 546.

184 *See id.* at 5. The agency has had to develop procedures to prevent contamination resulting from space travel. *See generally* SANDIA CORP., UNDER NASA CONTRACT NO. W-12324, CONTAMINATION CONTROL PRINCIPLES (1967).

the effects these contaminants may have on the environment.[185]

The OSTP developed field test requirements for biotechnology-derived plants.[186] Two of the requirements are relevant here. First, the level of containment should be commensurate with the level of environmental and other risks associated with the material being interjected.[187] Second, if release of a material presents unacceptable risks or the risks cannot be determined adequately, then confinement requirements must be especially rigorous.[188]

These examples provide several considerations that are applicable here. First, before releasing a potentially dangerous material, extensive study of its potential risks should be conducted. Second, if there is risk of serious damage to the environment, then efforts to contain the action's consequences should be implemented. Third, these efforts should escalate consistent with the level of risk involved.

I. *We Should Seek Solutions That Fully Resolve Problems*

A typical criticism leveled against SRM suggests another principle that should be considered. Commentators often charge that SRM technologies will not address the acidification of the oceans.[189] One might say this failure violates a principle of demanding a complete or perfect solution.[190]

This Article rejects this as a principle that should be applied when determining whether to deploy a geoengineering technology. First, requiring a perfect solution contradicts the acceptance of incomplete remedies, discussed above.[191] Second, society rarely develops complete solutions to problems, and it often implements

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185 *Id.* at 7.

186 Field Test Requirements for Biotechnology Derived Plants and To Establish Early Food Safety Assessments for New Proteins Produced by Such Plants, 67 Fed. Reg. 50,578 (proposed Aug. 2, 2002).

187 *Id.* at 50,579.

188 *Id.*

189 *See, e.g.*, Robock, *supra* note 43, at 15. Some critics of SRM assert that ocean acidification is a risk of SRM. Keith, *supra* note 66, at 1. As Keith and MacMartin note, ocean acidification does not result from SRM; instead, it results almost solely from CO_2 emissions. *Id.*

190 *See* Carol M. Rose, *Environmental Lessons*, 27 LOY. L.A. L. REV. 1023, 1032 (1994) (noting that partial solutions run counter to much of our legal tradition).

191 *See supra* note 58 and accompanying text.

an array of partial solutions. One example comes from the efforts to treat Human Immunodeficiency Virus (HIV). Because of characteristics of the virus that complicate treatment, singular medical treatments were unavailing.[192] Consequently, 30 years after the spread of HIV, the primary treatment for this condition involves a cocktail of drugs, each serving a unique purpose.[193] No one suggests that drugs that help address some of the symptoms of HIV should be rejected on the grounds that no single drug provides a complete solution. We should not require more of climate solutions.

III. APPLICATION OF THESE PRINCIPLES CAN GUIDE DECISIONS TO DEPLOY CLIMATE ENGINEERING

These legal principles can help guide decisions to deploy climate engineering technologies. Rather than make haphazard, *ad hoc* decisions, society can use these principles to develop a principled, reasoned, and replicable approach to determine whether to deploy a specific climate engineering technology. Furthermore, development of these principles before a climate emergency arises better ensures that an appropriate process is used to make decisions and that society does not act reflexively in the face of a possible climate catastrophe.

The remainder of this Article will develop a structure to apply these principles to some of the most commonly discussed geoengineering technologies. First, it will review considerations that arise when applying these principles to geoengineering in general. Next, it will address issues that courts and social scientists have confronted when decision makers utilize multi-factor tests. Finally, it will apply these principles to actual climate engineering technologies. Application to these technologies demonstrates that these principles can help to clarify the relative advantages and disadvantages of different approaches.

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192 Two aspects of HIV make it particularly difficult to treat successfully. First, it infects and kills the body's white blood cells, which are critical to its immune system. Second, the virus replicates itself imperfectly, causing it to mutate quickly. Alison Hill, *Why There's No HIV Cure Yet*, NOVA NEXT (Aug. 27, 2014), http://www.pbs.org/wgbh/nova/next/body/missing-hiv-cure/.

193 *See* Julie Verville, *Understanding the "AIDS Cocktail"*, HEALTHLINE (Feb. 19, 2013), http://www.healthline.com/health/hiv-aids/understanding-the-aids-cocktail#1.

A. *Some General Conclusions Concerning All Geoengineering Methods*

Before applying the principles to specific technologies, some general conclusions applicable to all climate engineering methods should be considered. Some considerations overlap, and certain principles, such as the moral hazard and the precautionary principle, raise issues that apply to all technologies. Thus, reviewing these considerations first will simplify the later process of applying the principles to particular technologies.

1. *The "Weak" Version of the Precautionary Principle Best Fits Climate Engineering*

The outcomes when applying two principles—the precautionary principle and the avoidance of a moral hazard—will likely be the same regardless of the technologies to which they are applied. First, we should exercise caution with all of these technologies. As discussed previously, lack of scientific certainty should trigger the precautionary principle.[194] We do not have scientific certainty concerning any of these geoengineering methods at this time,[195] and, perhaps, whenever we might need to deploy climate engineering, we will still lack scientific certainty.[196] Consequently, precaution should apply equally to all technologies. The question then becomes which version of the precautionary principle provides the better fit.

As noted previously,[197] the precautionary principle has both strong and weak versions. The strong version requires scientific certainty before deployment that a new technology will not harm the environment.[198] The weak version, on the other hand, operates more as a balancing system. Its calculus considers factors such as cost-effectiveness,[199] socio-economic costs[200] and environmental

194 *See supra* Section III.A.3.

195 For purposes of this discussion, this Article does not consider non-technological, natural fixes, such as "bio-geoengineering" methods, which would increase the planting of species with specific leaf glossiness to maximize solar reflectivity. For a discussion of this topic, see Andy Ridgwell et al., *Tackling Regional Climate Change by Leaf Albedo Bio-Geoengineering*, 19 CURRENT BIOLOGY 146, 150 (2009).

196 *Id.* at 149 (identifying climate issues that would need to be understood).

197 *See supra* notes 88–98 and accompanying text.

198 Patterson & Gray, *supra* note 76, at 437.

199 Sunstein, *supra* note 86, at 1012.

200 Patterson & Gray, *supra* note 76, at 437.

harms or benefits.[201] In this context, the weak precautionary principle, because of its breadth of factors and weighing process, is more appropriate than its stronger sibling.

2. *The Moral Hazard Objection Applies Equally (or Not at All) to All Geoengineering Methods*

Critics raise the moral hazard as one of their primary objections to climate engineering.[202] They charge that it will remove the incentive to reduce fossil fuel use.[203] Essentially, if society can avert the worst consequences of climate change through geoengineering, then the primary incentive to undertake the societal and lifestyle changes required to mitigate will diminish. Thus, society will continue with business as usual—either maintaining levels of fossil fuel use or even increasing their use—and rely upon climate engineering to avoid the worst effects of climate change.[204] Climate engineering will only treat the symptoms while ignoring the cause of the problem.[205] Even worse, it removes the incentive to address the cause.

Thus, resolution of the moral hazard, if it were to arise, appears to apply equally to all geoengineering technologies. Substantial research findings, however, question whether a moral hazard will actually develop. Researchers have found little indication that geoengineering will prompt problematic changes in behavior. They have conducted a number of studies to determine whether climate engineering might give rise to a moral hazard or to risk compensation behavior. In general, these studies found that support for geoengineering tended to be conditioned upon a simultaneous pursuit of mitigation.[206] Indeed, despite any benefits

201 *Id.*

202 The concept of moral hazard is discussed more fully in Section III.C.

203 *See* Davis, *supra* note 34, at 946–47 (identifying a common objection to geoengineering: that it might reduce the will to enact significant mitigation measures to reduce GHG emissions).

204 *See* Russell Powell et al., *The Ethics of Geoengineering* 2 (James Martin Geoengineering Ethics Working Grp., Working Paper), *available at* http://www.practicalethics.ox.ac.uk/__data/assets/pdf_file/0013/21325/Ethics_of_Geoengineering_Working_Draft.pdf.

205 *Id.*

206 *See* Adam Corner & Nick Pidgeon, *Geoengineering, Climate Change Skepticism and the 'Moral Hazard' Argument: An Experimental Study of UK Public Perceptions*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A 1, 4–5 (2014). Similarly, a GAO survey found that people are unlikely to consider geoengineering to be a substitute for mitigation. Lin, *supra* note 120 at 693.

of climate engineering, mitigation remains the preferred approach.[207] One study even found a possible reverse risk compensation effect—participants reported that they were more likely to support mitigation if the government pursued climate engineering.[208]

While this rationale may hold at the individual level, it may be less controlling at a broader level. For instance, geoengineering could provide a policy option which would ease political pressure to mitigate.[209] In this way, it could give rise to a moral hazard while also creating an intergenerational concern; the current generation would effectively "kick the can" of addressing climate change "down the road" to future generations.[210]

In conclusion, the evidence of a potential moral hazard is mixed. More pertinent here, however, nothing suggests that a moral hazard would be more likely to arise with one technology but not another. Thus, it would not provide a unique reason against deploying a particular technology, and it would serve questionable value as a separate principle.

3. *The Number of Principles Should Be Limited to Avoid Overwhelming Decision Makers*

An important consideration regarding the principles involves the process by which decision makers apply them. When applying checklists or extensive lists of factors, courts and researchers have recognized a number of approaches which can affect their utility.

Corner and Pidgeon conducted one of the most recent studies concerning moral hazard and analyzed participants' responses by different personality types. Corner & Pidgeon, *supra* note 206, at 11. They concluded that discussion of a possible moral hazard "may . . . simply reinforce existing beliefs" supportive or opposed to climate engineering. *Id.* at 12. Moreover, they concluded that utilization of geoengineering is not likely to reduce mitigation efforts; instead climate engineering will coexist with mitigation, just as adaptation efforts now do. *Id.*

207 INTEGRATED ASSESSMENT OF GEOENGINEERING PROPOSALS, PUBLIC AND OTHER STAKEHOLDER PERCEPTIONS OF GEOENGINEERING: FACILITATING RESPONSIBLE INNOVATION 2 (2014).

208 Reynolds, *supra* note 116, at 5–6.

209 Lin, *supra* note 120, at 707.

210 Reynolds, *supra* note 116, at 5. Conversely, deploying geoengineering will not necessarily reduce investment in mitigation by a comparable amount. Geoengineering implementation costs are likely to be small compared to those of mitigation and adaptation. *Id.* at 7. Furthermore, climate engineering, by cooling the planet, reduces mitigation and adaptation costs. *Id.*

Often courts weigh the components of legal checklists or legal tests equally.[211] Such an approach, however, is not always appropriate or desirable. Consequently, decision makers confronted with applying multiple criteria have adopted a number of different approaches. In some instances, courts eschewed merely totaling up the factors, favoring instead a "totality of the circumstances" approach.[212] This approach better assures that the court considers all of the facts and circumstances unique to every case, thereby best achieving fairness and equity.[213] Similarly, in other multi-factor determinations, decision makers applied a case-by-case determination, emphasizing flexibility in the application of a wide variety of factors.[214] In other cases, courts prioritized factors, recognizing that certain considerations carried greater importance than others.[215]

Decision makers, however, often do not apply multi-factor—or multi-principle—tests as they are intended. Social scientists have found that decision makers, when confronting complex decision processes, tend to limit the factors that they consider.[216] Empirical analysis in several contexts suggests that decision makers will seldom consider all relevant information when facing such decisions. Instead, at some point, they typically stop acquiring and analyzing information and commit to a decision.[217]

Thus, if the set of principles is too extensive, there is a risk that decision makers will disregard some of the principles. Therefore, some steps should be taken to assure that all of the principles are given their due. First, because of the tendency to ignore some factors in extensive lists, the set of principles to consider should not be exhaustive.[218] Second, resolution of some principles may address issues raised by other principles. Finally,

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211 *See* Zubulake v. UBS Warburg LLC, 217 F.R.D. 309, 322 (S.D.N.Y. 2003) (noting the tendency towards this type of application).

212 Noble v. United States, 231 F.3d 352, 359 (7th Cir. 2000).

213 Adam Schlusselberg, Comment, *In Re Davis*, 53 N.Y. L. SCH. L. REV. 639, 649 (2008–2009).

214 John S. Applegate, *Worst Things First: Risk, Information, and Regulatory Structure in Toxic Substances Control*, 9 YALE J. REG. 277, 302 (1992).

215 *Zubulake*, 217 F.R.D. at 323.

216 Barton Beebe, *An Empirical Study of the Multifactor Tests for Trademark Infringement*, 94 CAL. L. REV. 1581, 1601 (2006).

217 *Id.*

218 *Id.* at 1646.

the principles should be prioritized.[219] This will also provide a clearer signal to decision makers of the relative importance of each principle.

Applying these concepts to the principles identified above suggests several modifications for their application. Since an exhaustive list may be counterproductive,[220] the number of principles should be limited if possible. Fortunately, two of the principles—the precautionary principle and the moral hazard—are generally applicable to all climate engineering technologies and do not need to be considered separately for each technology. Moreover, three principles overlap. Determining whether a remedy is effective is essentially subsumed in the cost-benefit analysis determination. Likewise, the weak precautionary principle and cost-benefit analysis both weigh benefits against risks. Finally, the principle of natural state is awkward to apply, since it is difficult to benchmark.[221]

After this reduction, the following principles remain: cost-benefit analysis, consideration of alternatives, intergenerational equity, regional equity, reversibility, and containability.

4. *Decision Makers Should Prioritize the Remaining Principles*

Next, we must prioritize the remaining principles. A critical determination is whether the technology will work and what its associated risks will be. Similarly, to avoid focusing exclusively on a particular technology, and to clarify the choices that are available—including maintaining the status quo—the consideration of alternatives is also a top priority. Thus, the resolution of these two principles—cost-benefit analysis and consideration of alternatives—should be a top priority, and deployment should not proceed without favorable resolutions of them. Consistent with our societal concern in promoting equity and avoiding disparate impacts, the next priorities should be those

219 *Id.* (endorsing listing factors in the order of their greatest weight in a multi-factor test for trademark infringement).

220 *Id.* at 1601 (discussing empirical studies finding that decision makers typically reach decisions after considering a "remarkably low" number of factors). Considering the scientific expertise required for these determinations, one possible approach to reduce the risk that some principles will not be fully considered would be to establish different panels of experts to address a particular principle.

221 *See infra* note 228 and accompanying text.

principles targeted to avoiding such effects: intergenerational equity and regional equity. Finally, the decision makers should also consider reversibility and containability. While both of these concepts are important, the very nature of climate engineering may limit the ability of any technology to fully comply with these objectives. Nevertheless, any irreversible and extended consequences need to be considered.

5. *Decision Makers Should Maintain Flexibility When Applying the Principles*

One additional and important consideration is flexibility. Even courts applying extensive lists of factors realize that such lists are not necessarily complete.[222] Instead, these courts advocate flexibility in their application depending upon the circumstances of a particular decision.[223] Courts have especially recognized the importance of considering new factors not previously identified in circumstances involving emerging technologies.[224] Similarly, although this Article attempts to identify a complete set of legal principles that should bear on the deployment question, the author recognizes that unforeseen circumstances and technologies may arise necessitating additional considerations.

Finally, and perhaps most importantly, the conclusions drawn from the following application of these principles will change over time. These technologies are still in their infancy.[225] We can therefore rest assured that our knowledge of the application and effects of these technologies will evolve. Consequently, the conclusions drawn from the applications of these principles may change depending upon when a decision maker applies them. This will occur not just because of changes in the technologies but also because of changes in the global circumstances to which the results of climate engineering would be compared.[226] And, of course, all

222 *See* I.P. Lund Trading ApS v. Kohler Co., 163 F.3d 27, 43 (1st Cir. 1998) (acknowledging that the eight factors in a test to determine consumer confusion in trademark infringement cases are non-exclusive).

223 73 C.C.C.3d 348, 353 (Ont. Ct. Gen. Div. 1992).

224 *See* Douglas L. Rogers, *Ending the Circuit Split over Use of a Competing Mark in Advertising-the Blackstone Code*, 5 J. MARSHALL REV. INTELL. PROP. L. 157, 164–65 (2006).

225 *See* IPCC, *supra* note 17, at 7–64.

226 Toby Svoboda, *Is Aerosol Geoengineering Ethically Preferable to Other Climate Change Strategies?*, 17 ETHICS & THE ENV'T 111, 120 (2012) (recognizing that at a future date a mitigation strategy could create more harm

climate engineering technologies raise the possibility of unintended and unanticipated consequences.[227]

6. Decision Makers Should Apply the Resulting Framework to Combinations of Objectives and Geoengineering Technologies

The intended outcome of geoengineering deployment can be as important to its success as the actual method we utilize. This is because different applications of a particular technology can alter its outcome. While deploying climate engineering to return the climate to its previous state will risk a particular set of consequences, another set of outcomes are likely when the same technology is deployed to achieve a different objective, such as slowing the rate of warming. Thus, when applying the principles, decision makers must consider both the particular geoengineering technology and the purpose of its deployment.

Should the results of climate engineering be compared to a business-as-usual scenario or to pre-industrial conditions? Obviously, this decision could yield vastly different results. The issue arises because many critics of climate engineering compare its results to a pre-industrial climate.[228] With that baseline, they consider climate engineering to be "implementing highly untested and risky" technologies.[229] Others, however, argue that we are presently embarking upon another "highly untested and risky" experiment—the emission of greenhouse gases causing planetary warming at unprecedented speed.[230] They maintain that we have already embarked upon a series of geoengineering experiments[231]

than an aerosol geoengineering strategy).

227 *See* Gary Cooper et al., *Preliminary Results for Salt Aerosol Production Intended for Marine Cloud Brightening, Using Effervescent Spray Atomization*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A 1, 2 (2014).

228 The issue of choosing the appropriate benchmark underscores the difficulty of applying the natural state principle.

229 Noah Deich, *Are Negative Emissions a "Myth?,"* THE ENERGY COLLECTIVE (Dec. 12, 2014) http://theenergycollective.com/noahdeich/2169321/are-negative-emissions-myth.

230 *See, e.g.*, Noah S. Diffenbaugh & Christopher B. Field, *Changes in Ecologically Critical Terrestrial Climate Conditions*, 341 SCI. 486, 489–90 (2013) (compared to other extreme changes in the climate, i.e., the Eocene-Oligocene glaciation and the Pleocene-Eocene Thermal Maximum, the current rate of warming is occurring at speeds 10 to 100 times faster).

231 *See* ANDY RIDGEWELL ET AL., *supra* note 54, at 4164 (noting that climate engineering would represent the latest in a series of actions by humans, such as changing the albedo and hydrology of the land surface and, more recently,

that are at least as risky and uncertain as any proposed climate engineering would be.[232]

7. *The Principles Apply to the Decision Whether to Deploy a Particular Geoengineering Technology*

The purpose of the principles is to assist decision makers selecting among climate engineering technologies. The underlying premise of the principles is that circumstances will have forced society's decision to deploy geoengineering. This anterior decision whether to deploy *any* climate engineering, as opposed to whether to deploy a *particular* technology, is a separate question. Indeed, it has already been the subject of numerous articles.[233] Analytically, these two decisions concern different considerations and decision makers should make them separately.[234]

B. *Application of These Principles Suggests That Some Geoengineering Solutions Might Be More Acceptable Than Others*

Although these general conclusions about climate engineering deployment are possible, unique characteristics of each technology necessitate application of the principles on a technology-by-technology basis. The following Section applies the principles to a range of potential geoengineering methods. However, it directs particular attention to one technology: stratospheric aerosol

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changing the greenhouse composition of the atmosphere and chemistry of the ocean, that affect the climate).

232 *See, e.g.*, ROSE CAIRNS, DISCUSSION PAPER: WILL SOLAR RADIATION MANAGEMENT ENHANCE GLOBAL SECURITY IN A CHANGING CLIMATE? 26 (2014), http://www.geoengineering-governance-research.org/perch/resources/workingpaper16cairnssrmandsecurity.pdf; Joshi Herrmann, *Stealing Your Thunder: Why Geoengineering Is One of Science's Most Contested Terrains*, LONDON EVENING STANDARD (Feb. 20, 2015), http://www.standard.co.uk/lifestyle/london-life/stealing-your-thunder-why-geoengineering-is-one-of-sciences-most-contested-terrains-10055867.html ("Everything we know about geoengineering suggests it would be a bad idea. It's just a question of whether the alternative is even worse. If you think climate change is going to make the world a very bad place to live in, then geoengineering might be the better of the two evils.").

233 *See* Suvi Huttunen et al., *Emerging Policy Perspectives on Geoengineering: an International Comparison*, 2 ANTHROPOCENE REV. 14, 15–16 (2014) (reviewing the issues involved in deciding to utilize climate engineering and many of the seminal articles addressing this topic).

234 The two decisions might be considered akin to decisions involving whether a patient requires an invasive or other particular remedy (e.g, diet, lifestyle change, medicine, surgery) which will best address the patient's needs.

injection.

Among the SRM techniques, the one method most extensively discussed has been atmospheric particle injection.[235] This method consists of injecting particles, usually sulfur,[236] into the atmosphere to mimic the effects of volcanic eruptions.[237] Part of the technology's appeal arises because it derives from a natural process, volcanic eruptions, and the rapid cooling effects of numerous such eruptions are well documented.[238] Moreover, many scientists consider particle injection to be the "most promising" climate engineering system.[239] They consider it to be so for a number of reasons. Compared to other methods, particle injection would require less energy, be capable of relatively quick deployment, cost less, and could cool the planet rapidly.[240] Consequently, it is the most frequently discussed climate engineering system.[241]

A proper analysis of particle injection, however, first requires a determination of the purpose for which the system would be

235 *See generally* Rasch et al., *supra* note 31, at 4010 (noting that scientists have studied sulfate aerosols for many years because of their importance generally to the chemistry of the lower atmosphere and their specific effect following volcanic eruptions). Moreover, this method is one of the few methods for which a field test has been planned. Jack Stilgoe, Matthew Watson, & Kirsty Kuo, *Public Engagement with Biotechnologies Offers Lessons for the Governance of Geoengineering Research and Beyond*, PLOS BIOLOGY, Nov. 12, 2013, at 2. Because of a controversy that arose regarding related patent rights, however, the organizers canceled the experiment. Daniel Cressey, *Cancelled Project Spurs Debate over Geoengineering Patents*, NATURE, May 24, 2012, at 429.

236 Scientists have tested other materials, such as alumina and diamond, with promising initial results. *See* D.K. Weisenstein & D.W. Keith, *Solar Geoengineering Using Solid Aerosol in the Stratosphere*, 15 ATMOSPHERIC CHEMISTRY & PHYSICS DISCUSSIONS 11799, 11800 (2015).

237 *See* Rasch et al., *supra* note 31, at 4009.

238 For instance, when Mount Pinatubo erupted in 1991, it cooled the globe by approximately 0.5° C in less than one year. David W. Keith, Edward Parson, & M. Granger Morgan, *Research on Global Sun Block Needed Now*, NATURE, Jan. 28, 2010, at 426. After Mount Tambora's eruption in 1815, the subsequent cooling effect produced "the year without a summer." Stilgoe, Watson, & Kuo, *supra* note 235, at 1.

239 Seth D. Baum, Timothy M. Maher, Jr., & Jacob Haqq-Misra, *Double Catastrophe: Intermittent Stratospheric Geoengineering Induced by Societal Collapse*, 33 ENV'T SYSTEMS & DECISIONS 168, 168 (2013).

240 *Id.* at 171–72.

241 *See* Adam D.K. Abelkop & Jonathan C. Carlson, *Reining in Phaëthon's Chariot: Principles for the Governance of Geoengineering*, 21 TRANSNAT'L L. & CONTEMP. PROBS. 763, 777–78 (2013).

deployed. As discussed previously, scientists studying SRM technologies have concluded that the manner of deployment will determine the technology's risks and benefits as much as any other consideration.[242]

An accurate analysis of climate engineering technologies needs to begin with consideration of the objective for using them. Because of the termination effect,[243] a critical distinction turns on whether society were to deploy SRM to return the climate to its pre-warming level or instead to slow the rate of warming. In general, most of the studies of SRM assume that we would use these technologies to return the earth's climate to its pre-industrial condition.[244] Because this would require more extensive cooling,[245] the consequences of termination would be greatest under such deployment.[246]

Thus, certain deployments of SRM could raise concerns of intergenerational equity in two ways. First, if society used it in a manner that risked a termination effect, the current generation would be committing future generations to maintain the technology to avoid catastrophic consequences.[247] Second, investments in climate engineering would almost certainly divert some funds otherwise available for other climate change responses directed towards mitigation and adaptation.[248] In this way, it could create an intergenerational conflict, since the use of SRM could

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242 *See supra* notes 35–41 and accompanying text.

243 *See supra* notes 35–41 and accompanying text.

244 *See, e.g.*, Kelly E. McCusker et al., *Rapid and Extensive Warming Following Cessation of Solar Radiation Management*, ENVTL. RES. LETTERS, Feb. 17, 2014. McCusker et al., conducted an "ensemble" of SRM simulations, including 20-year and 80-year implementation periods, applying different climate sensitivity values, and projecting both 5-year and 20-year trends after cessation. *Id.* at 2, 5–6. Despite this breadth of analysis, they simulated only abrupt SRM termination. *Id.* at 5.

245 *See* Douglas G. MacMartin, Ken Caldeira & David W. Keith, *Solar Geoengineering to Limit the Rate of Temperature Change*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A 1, 11 (2014).

246 *See id.* at 11 (recognizing that limiting the deployment of geoengineering would reduce the risks associated with the technology).

247 *See* Holly Jean Buck, *Climate Remediation to Address Social Development Challenges: Going Beyond Cost-Benefit and Risk Approaches to Assessing Solar Radiation Management*, *in* ENGINEERING THE CLIMATE: THE ETHICS OF SOLAR RADIATION, *supra* note 48, at 142. This intergenerational concern arises because the current generation "locks-in" a commitment to geoengineering, thereby reducing the choices for its descendants. *Id.* at 143–44.

248 *See* Reynolds, *supra* note 116, at 7.

enable the current generation to force the greatest costs of mitigation and adaptation to be incurred by future generations.[249]

Alternatively, society might choose to deploy SRM only to slow the rate of warming or to partially offset the degree of warming.[250] The former would be beneficial, since, as noted previously, the rate of change is more harmful than the actual new global temperature.[251] Another objective might be to utilize SRM to buy time to implement additional mitigation and adaptation measures.[252] If society deploys SRM for these purposes, then less solar reduction will be required, and it will be needed over a shorter period of time.[253] Consequently, this will reduce the risks of using the SRM technology.[254] Furthermore, the termination effect might be avoidable if SRM's use were phased-out rather than abruptly stopped.[255] Alternatively, we might choose not to maximize cooling, but instead to minimize the effects of warming. This reduced geoengineering again would generate fewer or

249 *See* Patrick Taylor Smith, *Domination and the Ethics of Solar Radiation Management*, *in* ENGINEERING THE CLIMATE: THE ETHICS OF SOLAR RADIATION MANAGEMENT, *supra* note 48, at 43, 54. Conversely, a proponent of geoengineering might argue that SRM actually benefits future generations since it might better preserve species and ecosystems that would be destroyed by unchecked warming. Corner, *supra* note 170, at 942 (participant in workshop noted that geoengineering may provide a means to stabilize the earth for future generations).

250 *See generally* MacMartin, Caldeira, & Keith, *supra* note 245, at 2.

251 *See, e.g.*, Robock, *supra* note 39.

252 *See generally* MacMartin, Caldeira, & Keith, *supra* note 245, at 2.

253 *Id.*

254 *Id.* at 11. As Keith and MacMartin note, the ratio of SRM's benefits to costs will be largest for very small amounts of SRM. Keith & MacMartin, *supra* note 66, at 5.

255 *See* MacMartin, Caldeira, & Keith, *supra* note 245, at 6 (recognizing that the range of choices for ceasing solar geoengineering is not limited to the binary choice of terminate or continue but may also include phasing it out). Yet discussions of the termination effect typically contemplate this binary choice between termination and continuation. *Id.* at 11. While we can hope that the entity governing particle injection would be responsible enough to avoid an abrupt cessation, a catastrophe such as a war or a pandemic might prevent the continuation of the injections. In such case, a "double catastrophe" of a rapid temperature increase would compound the effects of the initial catastrophe. Seth D. Baum, *The Great Downside Dilemma for Risky Emerging Technologies*, 89 PHYSICA SCRIPTA 1, 4 (2014). If termination did not result from an initial catastrophe, the prospects are more encouraging. If SRM were terminated suddenly, a rapid re-initiation might reduce the termination effect. MacMartin, Caldeira, & Keith, *supra* note 245, at 6. A voluntary cessation, conversely, could involve a phase out at a rate that would reduce overall risk and damage. *Id.* at 11.

weaker side effects.[256]

In view of the significance of this distinction, this Article will apply the principles to particle injection, but it will do so first assuming we deploy the technology to return the plant's temperature to a pre-industrial level. Next, the article will consider deployment of this technology as proposed merely to reduce the rate of warming.

1. *Particle injection to cool to pre-industrial levels*

If we were to deploy particle injection (or probably all other SRM technologies) to cool the planet to a pre-industrial level, it would fail most of the principles:

1.Alternatives /Outweighing Benefits: These principles are combined because the answer to both principles would likely be circumstance dependent. Many scientists expect that particle injection would be used only to avert a climate catastrophe.[257] Thus, SRM deployment under such circumstances might be the best alternative and outweigh any anticipated risks, mainly because the circumstances at the time of deployment might be so dire. Under less dire circumstances, particle injection is less likely to be the best alternative or to outweigh its associated risks.

2.Intergenerational Equity: As indicated previously, the critical distinction between the two approaches concerns the consequences of using particle injection to restore a pre-industrial climate.[258] An immediate shut off of the injection system would return the climate to its pre-cooled temperature, but the temperature would rise at such a rapid rate that it might endanger many species and ecosystems.[259] Thus, this method would raise intergenerational concerns, since it commits future generations to maintenance of the injection system to avoid a cataclysmic rise in temperature.[260] Not only would future generations be committed to continue the system, research indicates that over time their

256 G. Bala, *Should We Choose Geoengineering to Reverse Global Warming?*, 107 CURRENT SCI., Nov. 10, 2014, at 1939–40.

257 Barrett, *supra* note 24, at 47.

258 Burns, *supra* note 28, at 47.

259 McCusker et al., *supra* note 244, at 1–2.

260 *See* Marion Hourdequin, *Climate Remediation to Address Social Development Challenges: Going Beyond Cost-Benefit and Risk Approaches to Assessing Solar Radiation Management*, *in* ENGINEERING THE CLIMATE: THE ETHICS OF SOLAR RADIATION, *supra* note 48, at 142.

commitment would need to increase, because the albedo reflectivity of the system would decline over time.[261]

3.Regional/Geographic Equity: Scientists project that particle injection would create significant regional disparities.[262] Essentially, regional differences inhere with particle injection. Scientists expect the technology to cause weather patterns to change adversely in many parts of the globe.[263] Over time, its use would cause different regions to experience varying climate modifications, including regional differences in precipitation.[264] Anticipated effects include a decrease in average annual precipitation in Africa, South America, and southeastern Asia.[265] Furthermore, the effects on temperature and precipitation would not only vary significantly, they would also follow different trajectories.[266]

4.Reversibility: Even if particle injection were "shut off" abruptly, the injected particles would remain in the atmosphere for up to five to ten years.[267] Thus, if the injection of particles was adversely impacting the environment—for instance, altering

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261 *See* P. Heckendorn et al., *The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone*, ENVTL. RESOURCE LETTERS, Nov. 13, 2009, at 1, 11. This results from a key difference between volcanic eruptions and sulfuric particle injection – the former is a singular event, while the latter will involve continuous repetition. Baum, Maher, & Haqq-Misra, *supra* note 239, at 173. Consequently, over time the newly-injected particles coagulate with previously injected particles, growing to a size that the combined particles gravitationally settle faster, shortening their atmospheric residence times. Heckendorn et al., *supra*, at 11. In addition, larger particles are less efficient in scattering shortwave radiation. *Id.* As a result, to maintain the same cooling effect, the amount of sulfur injected into the atmosphere would need to increase over time. *Id.* Thus, while commentators commonly analogize this technology to a natural process, significant distinctions arise in the manner of particle injection. Adam Corner & Nick Pidgeon, *Like Artificial Trees? The Effect of Framing by Natural Analogy on Public Perceptions of Geoengineering*, 130 CLIMATIC CHANGE 425, 429 (2014).

262 Svoboda, *supra* note 226 at 115–16.

263 Burns, *supra* note 28, at 40.

264 Nancy Tuana, *The Ethical Dimensions of Geoengineering: Solar Radiation Management through Sulphate Particle Injection*, (Pa. State Univ. & Nat'l Sci. Found., Working Paper No. 2, 2013), http://wp.me/p2zkRk-7B.

265 Burns, *supra* note 28, at 40.

266 Katharine L. Ricke, M. Granger Morgan & Myles R. Allen, *Regional Climate Response to Solar-Radiation Management*, 3 NATURE GEOSCIENCE 537, 537–41 (2010).

267 Baum, *supra* note 255, at 4. *But see* MacMartin, Caldeira & Keith, *supra* note 245, at 11 (identifying the residence time of aerosols as lasting between one and two years).

precipitation patterns more severely than anticipated—such consequences might not be reversible in the short term. Although global-scale effects on temperature and rainfall would eventually recover to pre-injection levels, significant lasting changes in regional patterns would remain.[268] Of course, the consequences of the termination effect – destruction of a significant portion of ecosystems and species[269] – could not be reversed.

5.Containability: This system would not satisfy containment, since its effects would be global.[270] Specifically, the technology operates by injecting sulfur particles into the atmosphere, where scientists would expect them to mix and disperse so as to affect "a larger area."[271] Similarly, sulfur eruptions from volcanoes mix in the atmosphere and diffuse solar radiation globally.[272]

Application of the principles to a pre-industrial cooling scenario suggests that this approach might be unduly risky. The principles indicate that this approach will have equity concerns, both intergenerational and regional. Also, its effects will not be containable. Although its effects might be reversible, at best this will occur only after several years. The principles suggest that this approach might be an acceptable response to a climate catastrophe, but even that conclusion relies upon the assumption that no other alternatives will be available to avert the catastrophe.

2. *Particle injection to constrain warming*

On the other hand, many of these concerns would not arise if we were to deploy particle injection to achieve different objectives, i.e., slowing the rate of warming or avoiding extreme warming. Specifically, an application of the principles would reach the following conclusions:

1.Alternatives/Outweighing Benefits: Again, this is assuming a climate emergency involving a rapid warming or a regional

268 INTEGRATED ASSESSMENT OF GEOENGINEERING PROPOSALS, PRACTICALITIES OF GEOENGINEERING: COULD THE DEVIL BE IN THE DETAIL? 3 (2014).

269 Burns, *supra* note 28, at 48.

270 Indeed, one scientist, Alan Robock, has suggested that any SRM method will significantly modify the global climate system because of non-local climate responses. John Latham et al., *Marine Cloud Brightening*, 370 PHIL. TRANSACTIONS ROYAL SOC'Y A 4217, 4248 (2012).

271 Rasch et al., *supra* note 31, at 4008.

272 *Id.* at 4032.

crisis,[273] few, if any, alternatives presently exist that could provide as rapid a cooling effect. Consequently, as above, particle injection would again likely satisfy these principles, though this conclusion would be circumstance-dependent. Furthermore, utilizing particle injection below its maximum level will be optimal, because the negative consequences of the system multiply faster than its benefits as the amount of solar geoengineering increases.[274]

2.Intergenerational Equity: Under this scenario, particle injection would be deployed only temporarily.[275] Consequently, such deployment would likely avoid the risk of the termination effect. First, it would be deployed with an endpoint in mind.[276] Thus, barring an accident or unexpected catastrophe, the deployers would likely have a plan to ratchet down the system.[277] Second, the need to maintain the system for a millennium is not inherent with particle injection, but instead results from the manner in which it is deployed.[278] Accordingly, such deployment could avoid triggering the termination effect. Thus, the intergenerational concern would be significantly reduced.

3.Regional/Geographic Equity: A limited deployment would produce fewer disparities in geographic weather. Reduced precipitation, for instance, depends entirely upon the magnitude of SRM applied.[279] Thus, applying less particle injection would minimize the risks of regional inequities.

4.Reversibility: Some of the consequences of particle injection would remain the same; if circumstances necessitated (or caused) an immediate cessation, then these particles and their effects would linger for several years.[280] Conversely, since this

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273 Barrett, *supra* note 24, at 47.

274 Keith & MacMartin, *supra* note 66, at 5; *see also* MacMartin, Caldeira & Keith, *supra* note 255, at 11 (reducing the amount of particle injection reduces the risks associated with the technology).

275 Keith & MacMartin, *supra* note 66, at 2.

276 MacMartin, et al, note that using SRM to constrain the rate of temperature change will inherently limit the period of deployment—models indicate that temperature increases eventually stabilize, thus obviating the need to continue SRM. MacMartin, Caldeira & Keith, *supra* note 255 at 3.

277 Keith & MacMartin, *supra* note 66, at 8 (discussing a method to slow the rate of warming which would have an implied commitment to a measured wind down).

278 Keith & MacMartin, *supra* note 66, at 2.

279 *Id.*

280 Latham, *supra* note 270.

approach would likely involve a gradual ratcheting up and down of the injection of particles,[281] a greater likelihood exists that its consequences will more quickly reverse. Plus, it contemplates a shorter deployment duration, which should increase the speed with which its consequences could be reversed.

5.Containability: Sulfur particles will scatter in the atmosphere and initiate global reactions.[282] Thus, the inherent characteristics of this technology will prevent its consequences from being limited in geographic scope.

Application of the principles to slow the rate of warming suggests that this approach would have reduced risk. While intergenerational and regional equity concerns could arise, they are less likely to arise when less particle injection is used. Similarly, the system would be easier to reverse if problems arose. While concerns remain, the principles suggest that this method would be worth serious consideration.

3. *Cloud brightening and cloud thinning*

Other SRM technologies also should be considered using the principles. Unfortunately, scientists have not studied other methods as thoroughly as they have particle injection. Nevertheless, this section will review two of the other prominent SRM technologies and discuss how the principles might apply to them.

Marine cloud brightening is a relatively new concept.[283] The technology would use fleets of ships to spray sea water into the air below marine clouds, thereby increasing the clouds' reflectivity and longevity.[284] Scientists project that this method could approximately counter-balance the warming caused by up to a doubling of atmospheric carbon dioxide.[285] They also expect this

281 Keith & MacMartin, *supra* note 66, at 9 (favoring a gradual and moderate implementation of SRM even if it were to be used to avert a climate emergency).

282 Rasch et al., *supra* note 31, at 4007.

283 Scientists first proposed marine cloud brightening around 2000. Piers Forster, *Not Enough Time for Geoengineering to Work?*, BULL. ATOMIC SCIENTIST (Feb. 2, 2015), http://thebulletin.org/not-enough-time-geoengineering-work7963.

284 P. J. Connolly et al., *Factors Determining the Most Efficient Spray Distribution for Marine Cloud Brightening*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A 1, 2 (2014).

285 John Latham et al., *Marine Cloud Brightening: Regional Applications*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A 1, 2 (2014).

method to be reasonably safe.[286] Supporting this conclusion are two aspects of this technology. First, it could be shut off almost immediately, "with essentially all of the sea water droplets returning to the ocean within a few days."[287] Second, this technology may enable scientists to limit its deployment to produce only a localized effect,[288] thereby reducing the likelihood of regional inequities. Nevertheless, some disparities would result since the cooling effect would occur only over the oceans.[289]

As discussed below, cloud brightening might pass muster with several of the principles:

1. Alternatives/Outweighing Benefits: The effects of cloud brightening are anticipated to be nonlinear and, thus, scalable. So, for instance, 25 percent of its potential cooling effect could be achieved with only 5–15 percent of the potential cloud seeding.[290] This aspect of the technology might enable minimization of negative consequences.[291] Also, in contrast to chemicals used in other aerosol proposals, seawater is both non-polluting and non-toxic,[292] further reducing the likelihood of adverse consequences. Nevertheless, scientists have identified potential risks. For instance, although it would likely reduce precipitation globally, it might actually increase runoff over land.[293] Moreover, cloud brightening's effects are expected to worsen, not reduce, both the

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286 Philip W. Boyd, *Ranking Geo-engineering Schemes*, NATURE GEOSCIENCE, Nov. 2008, 722, 724 (concluding that cloud whitening would be ranked second among five geoengineering methods on three measurements of safety).

287 Latham, *supra* note 270, at 4256. The global response to the system would, however, continue for "a much longer time." John Latham et al., *Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 3969, 3969 (2008) [hereinafter Latham, *Global Temperature Stabilization*]. This contrasts significantly with particle injection, whose particles would not fall from the atmosphere for at least one to ten years. Baum, *supra* note 267, at 4.

288 Latham, *supra* note 285, at 3. Indeed, this is one of the major benefits of this technology, since we may deploy it to mitigate or avert regional consequences, such as Arctic sea ice melting, *id.*, or sub-sea permafrost thawing. *Id.* at 5.

289 Latham, *Global Temperature Stabilization*, *supra* note 287, at 3982.

290 Latham, *supra* note 285, at 9.

291 *Id.*

292 *See* Cooper, *supra* note 227, at 2.

293 G. Bala et al., *Albedo Enhancement of Marine Clouds to Counteract Global Warming: Impacts on the Hydrological Cycle*, 37 CLIMATE DYNAMICS 915, 929 (2011).

warming and the drying experienced in parts of the globe, especially South America.[294] It would likely also cause regional changes in sea surface temperatures, which might alter ocean circulation patterns and modify regional weather systems.[295] Accordingly, the technology would still create risks, though, on balance, they might not outweigh its benefits.

Similar to particle injection, cloud brightening might only be used in the event of a climate catastrophe, particularly a melting of the ice caps.[296] Thus, the application of this principle will likely depend either upon the circumstances or the other available options. However, as discussed above, cloud brightening's reliance upon non-polluting substances and its inherently regional character may provide it with an advantage over other SRM technologies. Still, the consideration of alternatives would be important.

3.Intergenerational Equity: Because of the limited lifetime of its effects,[297] cloud brightening raises few intergenerational concerns.

4.Regional/Geographic Equity: As mentioned above, cloud brightening by its nature alters only oceanic clouds.[298] As a result, the technology's effects on land precipitation and distribution of cooling tend to differ from those induced by greenhouse gases.[299] As discussed above, in South America, it would actually enhance the warming and drying caused by greenhouse gases.[300]

5.Reversibility: As discussed before, cloud brightening's effects would be both short lived and relatively localized.[301] Thus, its direct consequences would be quickly reversible.

6.Containability: For largely the same reasons that support its

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294 *See id.*

295 David L. Mitchell, Subhashree Mishral & R. Paul Lawson, *Cirrus Clouds and Climate Engineering: New Findings on Ice Nucleation and Theoretical Basis*, *in* PLANET EARTH 2011 - GLOBAL WARMING CHALLENGES AND OPPORTUNITIES FOR POLICY AND PRACTICE 257, 258 (Elias Carayannis eds., 2011).

296 Latham, *supra* note 285, at 5–6.

297 Latham, *supra* note 270, at 4256.

298 Latham, *supra* note 285, at 1–2 (identifying marine cloud brightening as seeding marine stratocumulus clouds).

299 Andy Jones, Jim Haywood, & Olivier Boucher, *A Comparison of the Climate Impacts of Geoengineering by Stratospheric SO_2 Injection and by Brightening of Marine Stratocumulus Cloud*, 12 ATMOSPHERIC SCI. LETTERS 176, 180 (2010).

300 *Id.* at 180–81.

301 Latham, *supra* note 270, at 4248, 4257.

greater reversibility, cloud brightening's effects would be more containable than would be the effects of some other technologies, such as particle injection. Although the technology would alter only marine clouds, these changes would still have some effects over land.[302]

Application of the principles suggests that marine cloud brightening could be a promising technology. Nevertheless, despite these possible advantages, scientists acknowledge significant uncertainties concerning cloud brightening remain.[303] Of course, unintended consequences also could result.[304]

An even newer potential SRM technology[305] is cirrus cloud thinning.[306] This technology would apply a different approach to solar radiation: rather than reflect incoming sunlight, as do sulfur particle injection and marine cloud brightening, this method would reduce cirrus clouds to facilitate the release of outgoing radiation.[307] Cirrus clouds act similarly to greenhouse gases by trapping outgoing longwave radiation.[308] This climate engineering method would seed cirrus clouds with ice nuclei that reduce cloud coverage and cloud lifetimes.[309] Consequently, more longwave radiation would be able to escape the atmosphere.

Because of cloud thinning's recent conception, a full analysis under the principles would be especially premature. However, consideration of some aspects of the technology would still be informative. Cloud thinning's effects could be stopped within

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302 Jones, et al, *supra* note 299, at 180.

303 Partanen et al., *supra* note 41, at 1 (citing studies finding possible detrimental side effects, such as decreased precipitation over South America).

304 *See* Cooper, *supra* note 227, at 2.

305 Actually, some scientists consider this to constitute a third climate engineering branch, which they categorize as earth radiation management, or ERM, since it would adjust the troposphere to reduce surface temperatures. Mitchell et al, *supra* note 295, at 258.

306 Scientists first proposed this technology in 2009. T. Storelvmo et al., *Cirrus Cloud Seeding Has Potential to Cool Climate*, 40 GEOPHYSICAL RES. LETTERS, 178, 178 (2013).

307 John Latham, Philip J. Rasch & Brian Launder, *Climate Engineering: Exploring Nuances and Consequences of Deliberately Altering the Earth's Energy Budget*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A 1, 3 (2014).

308 Mitchell et al., *supra* note 295, at 259. In fact, the effect of cirrus clouds is so significant that scientists consider their life cycle and cloud coverage to be the second most important process affecting climate sensitivity. *Id.* The clouds also produce a cooling effect by reflecting sunlight. Nevertheless, overall they have a net warming impact. *Id.*

309 *Id.* at 259–60.

weeks,[310] limiting its intergenerational impacts. Furthermore, two possible seeding materials, bismuth trilodide and sea salt, are nontoxic,[311] thereby minimizing some of the possible risks of the technology. On the other hand, it may cause regional inequities by altering regional and seasonal weather patterns.[312]

C. *Application of the Principles Suggests Several Conclusions*

These applications of the principles demonstrate their value. Specifically, they illustrate the following:

- The importance of the threshold questions: Clarifying the objective sought when engineering the climate (return to pre-industrial state or slow warming) can significantly alter the conclusion about the consequences of particular technologies. Similarly, determining the baseline for comparison (business as usual or pre-industrial level) substantially impacts the perceived success of different technologies.
- The principles' value in highlighting distinctions among technologies: The principles provide a set of pre-established criteria with which to evaluate different technologies. The previous applications demonstrate that, even with these nascent technologies, the principles help distinguish among the benefits and risks of each method.
- The value of utilizing multiple principles to such decisions: Applying multiple criteria to these decisions increases the likelihood of a better decision. For instance, if a decision maker were to apply only the first two principles—consideration of alternatives and outweighing benefits—the two forms of particle injection appear comparable. Only when additional principles are considered do the distinctions between the applications become apparent.

CONCLUSION

Humanity's extraordinary impact on the climate will require

310 *Id.* at 262.

311 H. Muri et al., *The Climatic Effects of Modifying Cirrus Clouds in a Climate Engineering Framework*, 119 J. GEOPHYSICAL RES. ATMOSPHERES 3643, 4174, 4175 (2014).

312 *Id.* at 4189.

that we consider extraordinary responses. We may soon have technologies that can minimize the consequences of climate change. If we choose to implement a climate engineering regime, however, we need a set of principles that can help us determine the appropriate courses to take. The proffered principles derive from established legal doctrines. They enable us to develop a set of reasoned and replicable standards to apply to these technologies. Use of these principles can assist decision makers and society as a whole when deciding among different geoengineering technologies.