Environmental Silver Bullets

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New technologies to save the environment are everywhere. From privately funded gene drives aiming to eradicate invasive species on islands, to iron fertilization efforts intending to sequester carbon dioxide, technological silver bullets are seen by many as a critical hope in efforts to mitigate increasing environmental degradation and global-scale problems like climate change. Billions of dollars are being spent on developing and deploying these technologies, which have quickly won the hearts and minds of members of the public, governments, and corporations.

These technologies are a red herring, promising easy solutions when real change requires difficult engagement with complex social-ecological systems. Furthermore, many of these innovations pose risks on a planetary scale. These risks are largely unaddressed by currently regulatory regimes, allowing large-scale technologies intent on permanent environmental disruption to be deployed without legal oversight. The combination of private funding, public support, and lack of regulation for these high-risk technologies has already resulted in several high-profile disasters. Governance mechanisms are urgently needed to mitigate environmental risks and address growing inequities.

This Article documents the advent of emerging silver bullet environmental technologies, describing how private sector actors are driving the explosion of these solutions. Using research from several cases studies, this article shows how individuals with big visions and no significant expertise are increasingly championing these emerging technologies, inspired by a Silicon Valley ethos of disruption. These technologies evade existing environmental regulatory regimes. The proliferation of large-scale technologies single-handedly developed and deployed by wealthy philanthropists both triggers environmental concerns and exacerbates existing inequities in environmental management. This Article argues that both formal and informal accountability mechanisms for emerging

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technologies must be strengthened to prevent large-scale environmental consequences.

INTRODUCTION

In 2018, The Ocean Cleanup launched a giant floating boom with the goal of solving the oceans plastics crisis by sweeping plastics out of the water. The design quickly captured the imagination of the world, and Boyan Slat, the founder, was hailed as a boy genius, giving talks about his design to international leaders at the World Economic Forum's Davos meeting and TED Conferences.[1] The Ocean Cleanup successfully raised millions of dollars and became the Darling of the public, philanthropists, and policymakers globally.[2] But before the

1. *See, e.g.*, TEDxDelft, *Boyan Slat How the Oceans Can Clean Themselves*, TEDED (Aug. 28, 2012), https://ed.ted.com/on/WG6PwQob (showing Slat's original TEDx presentation); *Boyan Slat*, WORLD ECON. F., https://www.weforum.org/people/boyan-slat (last visited Dec. 15, 2022) (World Economic Forum profile praising Slat).

2. *See* Press Release, The Ocean Cleanup, The Ocean Cleanup Raises 21.7 Million USD in Donations to Start Pacific Cleanup Trials (May 3, 2017); Gloria Dickie, *Ocean Cleanup Struggles to*

project was deployed, large parts of the scientific community voiced concerns about the viability of the technology, as well as its impact on fragile marine ecosystems.[3] These concerns were ignored. Instead, the large-scale technology was launched with the explicit intention of permanently altering ocean ecosystems without any meaningful regulatory oversight or public accountability.

The deployment of The Ocean Cleanup is an indicator of what could be the future of technology deployed in the environment: public support and technological innovation drive rapid silver bullet interventions, while gaps in regulation allow large-scale private enterprises intent on permanently altering environmental conditions to move forward with no scientific or legal oversight. A new generation of tech billionaires are leading the charge on implementing many of these solutions.[4] Success in disrupting traditional markets has empowered wealthy technologists to look for solutions that can similarly disrupt wicked environmental problems.[5] The result is a new influx of large-scale technologies for the environment.[6]

For many, the deployment of The Ocean Cleanup and other innovative technologies is a much-needed glimmer of hope for combatting increasingly pressing and complex environmental threats. It is no surprise that these solutions have quickly gathered the support of wealthy individuals and wide swaths of the public: we all want to believe that human ingenuity will provide slick answers to protect future generations. The reality, of course, is that nothing is that simple. When it comes to environmental technologies, there are no silver bullets. Technological innovation is undoubtedly a cornerstone of responding to environmental threats, but this innovation must be integrated into larger social-environmental systems.

Fulfill Promise to Scoop up Plastic at Sea, REUTERS (Sept. 16, 2021), https://www.reuters.com /business/environment/ocean-cleanup-struggles-fulfill-promise-scoop-up-plastic-sea-2021-09-16/.

3. *See, e.g.*, Miriam Goldstein & Kim Martini, *The Ocean Cleanup, Part 2 Technical Review of the Feasibility Study*, DEEP SEA NEWS (July 14, 2014), http://www.deepseanews.com/2014/07/the-ocean-cleanup-part-2-technical-review-of-the-feasibility-study/.

4. *See* Jennifer Kahn, *Mark Benioff Bets on Cleanup Tech for Ocean Trash*, WIRED (Sept. 18, 2018), https://www.wired.com/story/wired25-marc-benioff-boyan-slat-ocean-cleanup-plastic/; Anne Q. Hoy, *Philanthropy Plays Increasing Role in Advancing Science*, AM. ASS'N FOR THE ADVANCEMENT OF SCI. (Nov. 28, 2016), https://www.aaas.org/news/philanthropy-plays-increasing-role-advancing-science.

5. *See* Jeremy Hance, *How Big Donors and Corporations Shape Conservation Goals*, MONGABAY (May 3, 2016), https://news.mongabay.com/2016/05/big-donors-corporations-shape-conservation-goals/.

6. This development reflects one that is happening not just in the environment. *See* TARA DAWSON MCGUINNESS & HANA SCHANK, POWER TO THE PUBLIC 57 (2021) (describing the prevalence of silver bullet technologies, "Nearly everyone has been in that meeting. The one where someone proposes a new piece of technology to solve a problem. Homelessness or hunger or the racial gap in school achievement will be solved by an app, or by Blockchain, or a new database, or sensors, or machine learning, or maybe facial recognition. No matter the industry, the field, or the place, people love to propose a technological silver bullet.").

Today's technological advances are happening amid historic wealth and power disparities in what some have called a "new Gilded Age."[7] Despite the promises of technology to open access and democratize participation, the benefits of technology are unlikely to be distributed equally across society.[8] Instead, emerging technological tools are championed and implemented by a wealthy elite, reinforcing and exacerbating existing environmental inequities. In other areas, the power of a growing class of wealthy oligarchs acting as philanthropists has raised widespread concerns about these individuals dictating social outcomes.[9] Yet, the impact of the wealthy few on environmental interventions has not been explored in depth. Understanding how technology operates within and in support of existing social structures is essential to understand the risks and opportunities that new technologies pose for the environment.

Environmental silver bullets also evade traditional legal treatment. Silver bullets by definition are new: operating in new areas, using new methods and capabilities. These new areas are also more likely to be free from substantive regulation.[10] Silver bullets should be realistically critiqued to ensure effective governance and accountability. Balancing the costs of new technologies against their benefits may show the clear need to deploy these solutions, but this decision making should not solely be left to the whims of billionaires. Tradeoffs are inherent in environmental law, but these tradeoffs should not take place in the dark.[11]

As these new technologies are deployed, environmental policy makers must consider whether appropriate measures exist to mitigate potential negative impacts. The Ocean Cleanup is a relatively mild scenario, with consequences limited to small-scale introduction of plastics into the ocean from a broken prototype and local ecosystem disruption.[12] Other technology interventions may not be so mild: from geoengineering projects that aim to alter atmospheric

7. DAVID CALLAHAN, THE GIVERS: WEALTH, POWER, AND PHILANTHROPY IN A NEW GILDED AGE 3 (2017).

8. *See* WORLD ECON. F., HARNESSING THE FOURTH INDUSTRIAL REVOLUTION FOR THE EARTH 10 (2017) ("There is a risk that technology, data, expertise and decision-making will become concentrated in the hands of a relatively small set of market leaders.").

9. *See* CALLAHAN, *supra* note 7, at 6–9; ANAND GIRIDHARADAS, WINNERS TAKE ALL: THE ELITE CHARADE OF CHANGING THE WORLD (2018).

10. *See generally* ROGER BROWNSWORD, RIGHTS, REGULATION AND THE TECHNOLOGICAL REVOLUTION (2008) (discussing the disconnect between emerging technologies and existing regulatory structures).

11. *See, e.g.*, Brian Tomasovic, *Tradeoffs in Environmental Law*, 34 J. LAND USE & ENV'T L. 93, 105–119 (2018).

12. That is assuming The Ocean Cleanup does not meet their goal of deploying globally, which would increase negative impacts dramatically. *See generally* THE OCEAN CLEANUP, https://theoceancleanup.com/oceans/ (last visited Dec. 15, 2022) (describing The Ocean Cleanup's global plans); Goldstein & Martini, *supra* note 3 (detailing the potential environmental impacts of The Ocean Cleanup's technology).

conditions, to gene drive controls, emerging technologies have the potential to do irreparable harm on a global scale.[13]

While geoengineering projects have raised concern from environmentalists, policy makers, and the legal community, the same cannot be said of other attempts to technologically alter environmental conditions.[14] The global public and the media have quickly latched onto many new silver bullet solutions to environmental problems, but scholarly critiques have not yet found a coherent voice. Some scholars worry about the environmental impacts of the reliance on emerging technologies, noting the high energy costs of technologies themselves.[15] Others worry that more powerful technologies will simply become tools to exploit environmental resources.[16] These concerns remain piecemeal, though.

Any apprehension about negative technological impacts is generally overpowered by enthusiasm for potentially revolutionary ways to get traction on wicked environmental problems. This enthusiasm spans sectors, with governments, the public, academics, and policymakers gushing about the opportunities new technologies are creating to improve environmental outcomes.[17] These emerging technologies are touted not just for the positive impacts they can have on the environment, but also for their potential to improve accessibility and participation in environmental issues.[18]

The primacy of private sector actors in creating and deploying environmental technologies contrasts with historical models of environmental governance that were dominated by government regulation.[19] A new era in

13. *See*, Hope M. Babcock, *The Genie Is Out of the De-Extinction Bottle A Problem in Risk Regulation and Regulatory Gaps*, 37 VA. ENV'T L. J. 170, 177–182 (2019); Albert C. Lin, *The Missing Pieces of Geoengineering Research Governance*, 100 MINN. L. REV. 2509, 2509–10 (2016).

14. *See* Randall S. Abate & Andrew B. Greenlee, *Sowing Seeds Uncertain Ocean Iron Fertilization, Climate Change, and the International Environmental Law Framework*, 27 PACE ENV'T L. REV. 555, 555–59 (2009).

15. *See, e.g.*, UN NEWS, *Sustainability Solution or Climate Calamity? The Dangers and Promise of Cryptocurrency Technology* (June 20, 2021), https://news.un.org/en/story/2021/06/1094362.

16. *See* JIM LEAPE ET AL., WORLD RES. INST., *TECHNOLOGY, DATA AND NEW METHODS FOR SUSTAINABLY MANAGING OCEAN RESOURCES* 23 (2020).

17. *See, e.g.*, Adelyn Zhou, *Blockchain Can Help us Beat Climate Change. Here's How*, WORLD ECON. F. (June 30, 2021), https://www.weforum.org/agenda/2021/06/blockchain-can-help-us-beat-climate-change-heres-how/; *AI for Earth*, MICROSOFT, https://www.microsoft.com/en-us/ai/ai-for-earth (last visited Dec. 22, 2022); *Artificial Intelligence and Technology Office*, U.S. DEPT. OF ENERGY, https://www.energy.gov/artificial-intelligence-technology-office (last visited Dec. 15, 2022); MCGUINNESS & SCHANK, *supra* note 6, at 58–59 ("Every agency, every nonprofit wants to believe that a widget or an app is going to fix their problems.").

18. For instance, through low-cost and open-source technologies allow members of the public to monitor air quality in their neighborhoods, to explore the oceans using remotely operated vehicles, to contribute to long term climate records by analyzing historical ship logs. *See, e.g.*, Christine Overdevest & Brian Mayer, *Harnessing the Power of Information through Community Monitoring Insights from Social Science*, 86 TEX. L. REV. 1493, 1509–12 (2008).

19. *See* Joshua Galperin, *Pragmatism, Pragtivism, and Private Environmental Governance*, 9 GEO. WASH. J. ENERGY & ENV'T L. 50, 53 (2018) (describing the prominence of different actors in the last century of environmental governance); Michael P. Vandenbergh, *Private Environmental Governance*, 99

environmental technology represents a dramatic shift not just in the capabilities available, but also in who is working to carry out environmental objectives.[20] Many scholars have recognized that thinking of technology as a discrete regulatory object provides little insight into governance needs and challenges.[21] This is certainly true when considering environmental technology. The capabilities and challenges created by new technologies must be considered in the context of existing environmental governance systems. Traditional environmental regulation is largely based around government action and discrete regulated industries.[22] New technologies are introducing actors and capabilities for which these models don't account. Taken together, these shifts will stress and redefine current models of environmental governance. New forms of environmental governance, both public and private, are needed to manage this changing field.

This Article characterizes the landscape of emerging environmental technologies that have arisen as part of rapid technological change in the twenty-first century, an era that some have dubbed the Fourth Industrial Revolution.[23] Part I begins by documenting the explosion in environmental technology capacity, arguing that the speed of deployment, scale of intervention, and democratization of access make this era different from previous periods of rapid technological change. This Part points specifically to the growth in large-scale, private sector technology interventions as definitive of this period, representing a significant shift from business as usual in environmental law.

Part II turns specifically to how private actors are using emerging environmental technologies. The landscape of environmental technology interventions is vast. From projects moving heat-adapted coral species across ocean basins to populate reefs at risk from warming temperatures, to genetic biocontrol projects aiming to eradicate invasive species on small islands, the methodologies, goals, and geographic scales of environmental interventions vary widely.[24] This Part describes the range of these solutions and shows the potentially high impact and low accountability of one class of technology

CORNELL L. REV. 129, 134 (2013) (showing the rise in private actors in environmental governance specifically).

20. *See, e.g.*, Rebecca Lave, *The Future of Environmental Expertise*, 105 ANNALS ASSOC. AM. GEOGRAPHERS 244, 246 (2015) (discussing the increasing role of the public in environmental decision-making).

21. *See* Lyria Bennett Moses, *How to Think About Law, Regulation and Technology Problems with Technology' as a Regulatory Target*, 5 L., INNOV. & TECH 1, 4–6 (2015); Meg Jones, *Does Technology Drive Law? The Dilemma of Technological Exceptionalism in Cyberlaw*, 2 J. L., TECH. & POL'Y, 249, 253 (2018).

22. *See* Galperin, *supra* note 19, at 53.

23. KLAUS SCHWAB, THE FOURTH INDUSTRIAL REVOLUTION 7 (2016).

24. Sarah Lazaras, *Heat-Resistant Corals in the Middle East Could Save the World's Dying Reefs*, CNN (June 28, 2018), https://www.cnn.com/2018/06/26/middleeast/middle-east-corals/index.html; Elizabeth Kolbert, *CRISPR and the Splice to Survive,* NEW YORKER (Jan. 11, 2021), https://www.newyorker.com/magazine/2021/01/18/crispr-and-the-splice-to-survive.

projects: those that are private, large-scale, and seeking to improve environmental conditions through active modifications.

Part III of this Article looks at several case studies illustrating the regulatory challenges from new technologies and identifying possible solutions for better environmental governance. Understanding the mechanisms that create environmental silver bullets and drive their widespread adoption is useful for identifying pathways for better accountability.

Part IV draws on these case studies to highlight how accountability must be addressed before emerging technologies can contribute positively to environmental governance regimes. New technologies lack both formal and informal accountability measures. Government regulations are in many cases ill-equipped to effectively govern these emerging technological solutions. Major federal command and control laws are unable to meet the challenges posed by technology interventions that are not polluting or harming ecosystems but are, rather, seeking to improve them. Laws that require environmental impact assessment, like the National Environmental Policy Act, often do not apply to these purely private projects that need no federal permits or financing. The result is that many of these new, large-scale technologies are operating in a formal governance gap, effectively unregulated by current environmental law. Strengthening regulatory regimes in addition to informal accountability mechanisms is essential for regulating emerging technologies moving forward.[25]

I. THE FOURTH INDUSTRIAL REVOLUTION IN THE ENVIRONMENT

New technological tools are emerging in all areas of environmental management. Many view Fourth Industrial Revolution innovations as gamechangers because of their potential to overcome some of the biggest challenges in environmental policy, from obtaining real-time, high-quality data on environmental conditions to remediating large areas of degraded ecosystems.[26] Others remain more skeptical about whether these technologies will be able to integrate effectively with existing complex management regimes.[27] In either case, new types of technology projects are fundamentally challenging existing environmental governance structures.

25. *See* Cary Coglianese, *Environmental Soft Law As a Governance Strategy*, 61 JURIMETRICS 19, 20–21 (2020); Gary E. Marchant, *Governance of Emerging Technologies as a Wicked Problem*, VAND. L. REV. 1861, 1866–68 (2020); Ryan Hagemann et al., *Soft Law for Hard Problems The Governance of Emerging Technologies in an Uncertain Future*, 17 COLO. TECH. L. J. 37, 40–42 (2018).

26. *See, e.g.*, Daniel C. Esty, *Environmental Protection in the Information Age*, 79 N.Y.U. L. REV. 115, 156–57 (2004); Amy L. Stein, *Artificial Intelligence and Climate Change*, 37 YALE J. REGUL. 890, 898–900 (2020); SCHWAB, *supra* note 23, at 64–66.

27. *See, e.g.*, Patrik Söderholm, *The Green Economy Transition the Challenges of Technological Change for Sustainability*, 3 SUSTAINABLE EARTH 1, 1–2 (2020); Grant Wilson, *Minimizing Global Catastrophic and Existential Risks from Emerging Technolologies through International Law*, 31 VA. ENV'T L. J. 307, 339–48 (2013); MCGUINNESS & SCHANK, *supra* note 6, at 68 ("Technology is a tool, an enabler, but rarely itself a solution.").

This Part characterizes the current landscape of environmental technology use. It asks critically whether this era of technological innovation is any different today from technological developments in the past. It argues that concurrent developments in speed, scale, and availability of technology are providing challenges for environmental governance that differ meaningfully from other periods of rapid technological change. Some of these challenges stem from the newness of technologies: the rapid pace of change means that many of these technologies are operating in regulatory voids.[28] This is a temporary problem that could end when governments implement regulations that control these technologies. Other challenges are more durable, stemming from the scale of environmental intervention that is now possible. This scale raises issues of how to control the magnitude of impact as well as how to mitigate associated environmental justice concerns.

A. Characteristics of 4IR Technologies

The current era of technological innovation is different from those that have come before. Some have gone so far as to call this the Fourth Industrial Revolution.[29] The Fourth Industrial Revolution (4IR) is characterized by the development of artificial intelligence (AI), robotics, virtual reality, blockchain, and other disruptive technologies.[30] The scale of potential technological intervention is rapidly expanding as AI and other tools come online.[31] Low-cost and participatory technologies, including blockchain, are creating transformative opportunities for new actors to access and participate in environmental governance.[32] And the exponential speed at which new technologies are being developed and deployed magnifies their potential for profound change.[33] Exponential increases in processing power and storage space are facilitating new management capabilities.[34] Taken together, the concurrent improvements in

28. *See* Moses, *supra* note 21, at 7 (describing this as technology's "pacing problem").

29. Klaus Schwab, *The Fourth Industrial Revolution What it Means, How to Respond*, WORLD ECON. F. (Jan. 14, 2016), https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

30. Devon McGinnis, *What is the Fourth Industrial Revolution*, SALESFORCE (Oct. 27, 2020), https://www.salesforce.com/blog/what-is-the-fourth-industrial-revolution-4ir/.

31. *See* Stein, *supra* note 26, at 891–92; Aakash Lamba et al., *Deep Learning for Environmental Conservation*, 29 CURRENT BIOLOGY R977, R978–81 (2019); Lucas N. Joppa, *AI for Earth*, 552 NATURE 325, 325 (2017).

32. *See* MIRIAM DENIS LE SEVE ET AL., ODI, DELIVERING BLOCKCHAIN'S POTENTIAL FOR ENVIRONMENTAL SUSTAINABILITY 3 (2018); LEAPE ET AL., *supra* note 16, at 20.

33. Schwab, *supra* note 29 ("There are three reasons why today's transformations represent not merely a prolongation of the Third Industrial Revolution but rather the arrival of a Fourth and distinct one: velocity, scope, and systems impact.").

34. *See* Esty, *supra* note 26, at 158–60; Ryan P. Kelly, *Will More, Better, Cheaper, and Faster Monitoring Improve Environmental Management?*, 44 ENV'T L. 1111, 1114–15 (2014).

speed, scale, and accessibility of environmental technologies are ushering in a new and potentially transformative era of environmental management.[35]

1. Scale

New technologies are creating opportunities to understand and alter ecosystems at previously impossible scales. From technologies that are powerful enough to have impacts at a global level, like atmospheric alteration tools, to those that are low-cost and accessible enough that they can be deployed densely across ecosystems, like new sensors, 4IR technologies create opportunities to use resources more efficiently and achieve better environmental outcomes.[36] The large-scale impacts of these technological innovations are a double-edged sword, creating both the opportunity for transformative positive impact at the same time that they open the door to more efficient resource exploitation and other global environmental consequences.

Big Data and AI capabilities combined with low-cost monitoring technologies are vastly improving environmental monitoring and science. Understanding ecosystem conditions and human uses is essential for crafting appropriate management strategies, but persistent logistical challenges and resource limitations have led to ongoing and widespread data gaps.[37] What data does exist is often not available at the geographic or temporal scales needed to effectively inform management decisions.[38] But, reductions in the cost of sensors and improvements in communication infrastructure are making it feasible to create robust environmental monitoring networks.[39] Combining on-the-ground data with increasingly detailed remote sensing information provides powerful insights into environmental conditions.[40] Alongside these big data sources, advanced machine learning analytics allow policymakers and environmental managers to understand environmental conditions across enormous spatial scales and create robust models that project conditions into the future.[41]

These monitoring improvements are just as important in the private sector, where companies' success depends on understanding environmental conditions. The need for accurate information on soil nutrition in agriculture, for instance, has driven many advances in sensor development.[42] Shipping and other logistics

35. Whether these transformations produce positive or negative, or more likely very mixed, outcomes for environmental law remains to be seen.

36. *See generally* WORLD ECON. F., *supra* note 8.

37. *See* Eric Biber, *The Problem of Environmental Monitoring*, 83 U. COLO. L. REV. 1, 34–35 (2011).

38. *See id.* at 21–22.

39. *See id.* at 31–32; Kelly, *supra* note 34, at 1113–15.

40. *See, e.g.*, *About*, GLOB. FOREST WATCH, https://www.globalforestwatch.org/about/.

41. *See, e.g.*, David A. Kroodsma et al., *Tracking the Global Footprint of Fisheries*, 908 SCIENCE 904 (2018) (describing how machine learning techniques can be used to analyze public available vessel data to understand vessel behavior at ocean basin scales).

42. Heyu Yin et al., *Soil Sensors and Plant Wearables for Smart and Precision Agriculture*, 33 ADVANCED MATERIALS 1, 15 (2021).

companies depend on highly accurate storm modeling to reroute and avoid major losses.[43] Improvements in sensor quality and data processing are driving private sector advances in environmental monitoring.[44] While these same advances are being used in government, commercial applications are leaps and bounds ahead.[45] Highly sophisticated sensor suites allow companies to monitor environmental conditions in real-time and at hyperlocal scales.[46] Coupling these new sources of data with machine learning algorithms allows companies to make minute and automatic operational changes in response to changing environmental conditions.

Emerging technologies are also being used directly to improve and remediate degraded environmental conditions. From small-scale projects aimed at reintroducing a single species, to large, multi-ecosystem projects intended to comprehensively protect and improve biodiversity, restoration efforts span every imaginable area of environmental degradation and are an important feature of environmental management.[47] In the past, these efforts have been limited both by funding and by the difficult logistics of successfully carrying out environmental restoration.

Ecosystem degradation generally happens because of compounding impacts.[48] Improving ecosystem health requires a holistic approach that may involve addressing many different causes of environmental degradation, from development, to pollution, to human uses such as overharvesting.[49] Emerging technology is expanding the conservation and restoration projects that both public and private sector actors can tackle. Projects that were once impossible,

43. Emily Heaslip, *How Maritime Weather Forecasting Minimizes Risks in Shipping Operations*, SOFAR, https://www.sofarocean.com/posts/how-maritime-weather-forecasting-minimizes-risks-in-shipping-operations (last visited Feb. 10, 2022).

44. *See id.*

45. Antonio Neri, *The Public Sector Must Accelerate Digital Transformation – Or Risk Losing Sovereignty and Trust*, WORLD ECON. F. (May 23, 2022), https://www.weforum.org/agenda/2022/05/the-public-sector-must-accelerate-digital-transformation-or-risk-losing-sovereignty-and-trust/ (noting that "The private sector's digital transformation has clearly outpaced that of the public sector.").

46. *See generally* DELOITTE, USING SMART SENSORS TO DRIVE SUPPLY CHAIN INNOVATION (2018) (overviewing smart sensor use in supply chains).

47. *See generally* Britta L. Timpane-Padgham et al., *A Systematic Review of Ecological Attributes that Confer Resilience to Climate Change in Environmental Restoration*, 12 PLOS ONE 1 (2017) (describing environmental restoration projects generally); *see also, e.g.*, Press Release, U.S. Dept. of Interior, Interior Clears the Way for Return of Whooping Cranes to Louisiana (Feb. 7, 2011) (describing single species restoration of whooping cranes); Marieke M. van Katwijk et al., *Global Analysis of Seagrass Restoration The Importance of Large-Scale Planting*, 6 J. APPLIED ECOLOGY 567 (2016) (describing localized ecosystem restoration of seagrass); Ricardo Ribeiro Rodrigues et al., *Large-Scale Ecological Restoration of High-Diversity Tropical Forests in SE Brazil*, 261 FOREST ECOLOGY & MGMT. 1605 (2011) (describing large-scale, multi-ecosystem restoration of tropical rainforests).

48. *See* Stefano Menegon et al., *Addressing Cumulative Effects, Maritime Conflicts and Ecosystem Services Threats Through MSP-Oriented Geospatial Webtools*, 163 OCEAN & COASTAL MGMT. 417, 417–18 (2018).

49. *See, e.g.*, Jason R. Rohr et al., *Community Ecology as a Framework for Predicting Contaminant Effects*, 21 TRENDS ECOLOGY & EVOLUTION 606, 610–61 (2006) (discussing community ecology as a holistic approach to addressing ecotoxicology).

for instance, moving the bounds of protected habitat as endangered species move throughout ecosystems, are now achievable.[50]

Large-scale technological solutions are particularly impactful for large-scale environmental problems, like climate change, for which older technologies haven't facilitated meaningful progress.[51] Technological advances are creating opportunities for planet-level solutions, like geoengineering technologies that can mitigate climate change using mirror-like deflectors in the atmosphere, or manipulation of ocean ecosystems to increase uptake of carbon dioxide.[52] While the positive outcomes of these technologies may ultimately be critical to adapt to climate change, the potential consequences are also substantial.[53] Altering atmospheric conditions could cause destabilizing impacts around the globe.[54] Geoengineering technologies are thus rightly controversial and establishing appropriate governance mechanisms is an established global priority.[55] Regardless of whether the international community ultimately decides the benefits of deploying these technologies are worth the considerable risks, it is undeniable that technological capabilities have the potential to cause significant harm at the same time that they provide new solutions to complex environmental problems.

The scale at which emerging technologies can operate is opening new frontiers for resource exploitation, in addition to ecosystem restoration.[56] As one example, deep-sea nodules of rare earth minerals have long been potentially attractive commercial prospects.[57] However, the logistical challenges and cost of mining three miles beneath the ocean surface have prevented the extraction of

50. LEAPE ET AL., *supra* note 16, at 16–17.

51. For instance, technological advances are necessary underpinnings of the shift to renewable energy. Without sophisticated energy generation and storage technologies, widespread use of renewables would not be possible. *See, e.g.*, Mary Beth Gallagher, *The Race to Develop Renewable Energy Technologies*, MIT NEWS (Dec. 18, 2019), https://news.mit.edu/2019/race-develop-renewable-energy-technologies-1218 (describing the technological advances needed to support renewable energy infrastructure).

52. Lin, *supra* note 13, at 2514.

53. *See, e.g.*, Grant S. Wilson, *Murky Waters Ambiguous International Law for Ocean Fertilization and Other Geoengineering*, 49 TEX. INT'L L. J. 507, 521–22 (2013) (discussing the unintended impacts of ocean iron fertilization efforts).

54. *See, e.g.*, Joseph Versen et al., *Preparing the United States for Security and Governance in a Geoengineering Future*, BROOKINGS (Dec. 14, 2021), https://www.brookings.edu/research/preparing-the-united-states-for-security-and-governance-in-a-geoengineering-future/ (describing climate geoengineering's possible destabilizing impacts); Lin, *supra* note 13, at 2509–15 (providing examples and an overview of geoengineering concerns).

55. *See, e.g.*, *id.* at 2512–13 (discussing the controversy surrounding geoengineering and the need for more robust governance frameworks).

56. *See, e.g.*, Clive Schofield, *New Marine Resource Opportunities, Fresh Challenges*, 35 U. Haw. L. Rev. 715, 720–32 (2013) (describing the new resource frontiers being opened in the ocean by technology, from hydrates to marine genetic resources).

57. Steven J. Burton, *Freedom of the Seas International Law Applicable to Deep Seabed Mining Claims*, 29 STAN. L. REV. 1135, 1137–38 (1977) ("Commercial attention now is focused on vast deposits of manganese nodules lying on the deep ocean floor . . .").

these resources.[58] Recent technological developments are shifting these calculations, with autonomous robotic machines making deep-sea mining commercially viable for the first time.[59] Opening up new areas of economic action may be an important component in augmenting global supplies of rare metals, but it also opens the door to new levels of environmental impact. Some have called the impacts of deep-sea mining "probably. . . the largest footprint of any single human activity on the planet."[60]

2. Accessibility

Technology is also changing how different actors engage in environmental governance. Governments and private sector companies are using technology to accelerate and improve existing capabilities. While new technologies may dramatically improve the way that environmental governance is carried out, for the most part technologies are helping regulatory bodies execute existing duties more effectively.[61] EPA and other federal agencies will still strive to regulate impacts on the environment through existing environmental laws. Technology adds new tools to the toolbox in carrying out these duties, but it does not fundamentally reshape what EPA and other federal agencies are required to do, at least in the short term.[62]

This is not true in the case of individuals. Environmental technology is not just improving existing capabilities, but also fundamentally reshaping how individuals engage in environmental governance.[63] In some cases, this is as basic as allowing individuals to participate in different types of environmental governance for the first time. In other cases, it is dramatically expanding the scope of what is possible on an individual level. While scholars have recognized the importance of private environmental governance, these discussions have primarily been limited to corporate action.[64]

The rise in individual participation in environmental governance has already begun to define this era, and it is enabled by current technological

58. *Id.* at 1137–39.

59. Christiana Ochoa, *Contracts on the Seabed*, 46 YALE J. INT'L L. 103, 106–08 (2021).

60. Kevin Douglas Grant, *Deep-Sea Mining Could Make Largest Footprint of Any Single Human Activity on the Planet'*, PRI: THE WORLD (Dec. 19, 2013), https://www.pri.org/stories/2013-12-19/deep-sea-mining-could-make-largest-footprint-any-single-human-activity-planet.

61. *See, e.g.*, *Digital Strategy*, EPA, https://www.epa.gov/data/digital-strategy (last updated Nov. 15, 2022) (describing EPA's Digital Government Strategy, which hinges on improving data publication and communication tools to better inform the public of EPA activities).

62. That is not to say that we may not reach this point in the future. Technology may improve to the extent that for instance, active restoration projects become feasible and Congress passes new legislation to drive this. Though even large shifts like this still fall within existing government duties to restore and conserve ecosystems nationally.

63. *See* Overdevest & Mayer, *supra* note 18 (discussing the growing role of individuals in local environmental monitoring and enforcement).

64. *See, e.g.*, Vandenbergh, *supra* note 19, at 147–61.

advances.[65] There are two major parts to this story: one is of tentative hope to improve accessibility and involve new and underrepresented segments of the population in environmental decision making. The other is of caution, with wealthy individuals driving major changes to the environment with little effective governmental or societal oversight. These two extremes illustrate truths about the role of technology outside of just environmental governance. In many ways, they reflect historical trends in participation that value wealthy, privileged communities and their environments over communities of lower socio-economic status.[66] Understanding how emerging technologies can and should contribute to environmental goals is an important step in remediating historic environmental justice issues.

Individuals have a long history of engaging in environmental protection, but environmental nonprofits have typically played a substantial role in mediating these efforts.[67] Individuals may choose to help directly with restoration efforts by participating in local volunteer organizations, or they may choose to support by filing citizen suits to spur restoration action.[68] Rarely have individuals carried out environmental restoration projects on their own.

Technology has enabled a new era of individual engagement in environmental governance. This engagement runs across a spectrum, allowing new forms of democratic participation at the same time as it gives wealthy individuals and private sector actors additional mechanisms to broaden their impact on environmental outcomes.

On the participatory side, citizen science projects are emerging globally and allow members of the public to collect scientific data that forms the basis for environmental management decisions. Many see this as the logical extension of the "gentleman naturalists" of the eighteenth and nineteenth centuries, who journeyed to remote areas of the world to discover new species in the name of science.[69] What differs today is the scope of members of the public who can engage in these types of projects. Where once science was reserved for wealthy, European men who were able to embark on multi-year journeys to other parts of the world, today citizen science is accessible to anyone with a computer or cell

65. *See* Adam Babich, *The Unfulfilled Promise of Effective Air Quality and Emissions Monitoring*, 7 GEO. ENV'T L. REV. 569, 601–03 (2018).

66. *See generally* Alice Kaswan, *Environmental Justice and Environmental Law*, 24 FORDHAM ENV'T L. REV. 149 (2017); Richard J. Lazarus, *Pursuing "Environmental Justice" The Distributional Effects of Environmental Protection*, 87 NW. U. L. REV. 787 (1993).

67. *See, e.g.*, Overdevest & Mayer, *supra* note 18, at 1509.

68. *See* Barton Thompson, *The Continuing Innovation of Citizen Enforcement*, 2000 U. ILL. L. REV. 185, 185–87 (2000).

69. *See* Lave, *supra* note 20, at 245–47.

phone.[70] This broadens participation in environmental governance and potentially yields better outcomes.[71]

Technology has vastly expanded the scientific endeavors in which members of the public can participate. The same low-cost sensors that are expanding government environmental monitoring are also being used by the general public to collect data on local conditions.[72] This engagement allows communities to identify and prioritize issues that are most important to them and use information they collect to directly engage in the regulatory process.[73] Sometimes individuals engage in response to perceived threats, for example monitoring industrial facility pollution.[74] Other efforts are intended to increase scientific knowledge by gathering data from a diverse group of individuals to increase coverage. The International NGO Reef Check is one of the largest efforts of this kind: recreational divers have been collecting basic data on reef health and fish abundance at thousands of sites around the globe for the last two decades.[75] The benefits of involving citizens in environmental monitoring include gathering more spatially and temporally robust datasets at lower costs, as well as providing ancillary participation and education benefits to the individuals participating in scientific studies.[76]

Citizen science efforts have been successful in identifying polluting activities, and they have led to major settlements and court cases.[77] In one recent example, tree DNA samples were successfully used in court to identify illegal logging in Washington and convict the perpetrators.[78] This DNA sampling technology is now being deployed widely by citizen scientists to create genetic databases of threatened tree species, and it can be used to identify and prevent poaching in the future.[79]

Nonprofits are facilitating these efforts in many ways, building on their traditional role of providing accountability to the public. Nonprofit efforts to identify public and private sector shortcomings have enabled critical progress on

70. Jonathan Silvertown, *A New Dawn for Citizen Science*, 24 TRENDS IN ECOLOGY & EVOLUTION 467, 467 (2009).

71. *See* Anna Wesselink et al., *Rationales for Public Participation in Environmental Policy and Governance Practitioners' Perspectives*, 43 ENV'T & PLAN. 2688, 2690–92 (2011).

72. *See* Overdevest & Mayer, *supra* note 18, at 1510–12.

73. *Id.* at 1510–14.

74. Gwen Ottinger, *Buckets of Resistance Standards and the Effectiveness of Citizen Science*, 35 SCI., TECH., & HUM. VALUES 244, 245 (2009).

75. *About*, REEF CHECK, https://www.reefcheck.org/about-reef-check/ (last visited Dec. 15, 2022).

76. There are of course limitations to citizen science projects. Costs to train volunteers and run studies over the timescales needed for robust scientific data are high. Many organizations underestimate these costs and build programs that are unsustainable and ultimately contribute less than anticipated. There are additional concerns about the quality of data collected by volunteers instead of experts.

77. *See* Ottinger, *supra* note 74 (discussing, for example, the citizen science that underlied litigation against a Shell Chemical Plant in Louisiana).

78. Press Release, U.S. Dep't of Just., Timber Thief Convicted Following 6-Day Trial (July 9, 2021).

79. *See Timber Tracking*, ADVENTURE SCIENTISTS, https://www.adventurescientists.org/timber.html (last visited Dec. 15, 2022).

environmental issues, and technologies are improving this capability. In recent years, many more nonprofits have begun acting in a watchdog role and providing the public with near real-time information on environmental conditions around the world. Global Forest Watch, for instance, was started in 2014 to monitor forest cover globally and identify areas that were being rapidly deforested.[80] Since then, a slew of other global "watches" have been created to provide the public with transparent information on the environment.[81]

Just as technology is facilitating new types of engagement for members of the public, it is also facilitating new philanthropic activities by a specific class of wealthy individuals. Enabled by technology, wealthy donors and philanthropists are driving large-scale, potentially transformative interventions in the environment. While wealthy individuals have always played important roles in environmental conservation, the potential scope of their impacts is increasing exponentially. Instead of setting aside property for conservation, wealthy individuals looking to have an impact can now singlehandedly change the course of environmental outcomes with strategic technology choices.[82] This is reflective of a broader trend in philanthropy, with the American Association for the Advancement of Science and others noting the increasingly important role of philanthropic funding in advancing scientific outcomes across disciplines.[83]

Whether emerging technologies will solve wicked environmental problems or instead facilitate environmental collapse depends on who will primarily be deploying those technologies. In the hands of environmental managers or non-profit actors, technology has the potential to dramatically improve capabilities and facilitate positive environmental outcomes. In the hands of the private sector, emerging technologies are more likely to facilitate the potential overuse of natural resources.

Historically, technological advancements have been adopted more quickly by the private sector, generally resulting in increased exploitation of the environment.[84] Improved detection technologies allow petroleum companies to find new oil fields or fishermen to locate schools of tuna more easily, leading to faster depletion of these resources.[85] There is no reason to believe that the same trend will not continue in today's era of emerging technologies. New robotic

80. *About*, GLOB. FOREST WATCH, https://www.globalforestwatch.org/about/ (last visited Dec. 15, 2022).

81. *See, e.g.*, *About*, RES. WATCH, https://resourcewatch.org/about; GLOB. FISHING WATCH, https://globalfishingwatch.org/.

82. For instance, through the deployment of massive iron fertilization "experiments." *See* Karen N. Scott, *International Law in the Anthropocene Responding to the Geoengineering Challenge*, 34 MICH. J. INT'L L. 309, 354 (2013).

83. Hoy, *supra* note 4.

84. *See* LEAPE ET AL., *supra* note 16, at 23.

85. *See, e.g.*, S. Gaci & O. Hachay, *Where and How Can We Find New Sources of Oil and Gas?*, EOS (May 10, 2017), https://eos.org/editors-vox/where-and-how-can-we-find-new-sources-of-oil-and-gas (discussing oil detection technology); Ginglian Hou, *Application of Feature Point Matching Technology to Identify Images of Free Swimming Tuna Schools in a Purse Seine Fishery*, 9 J. MAR. SCI. & ENG'G 1357 (discussing tuna detection technology).

capabilities are opening entirely new areas to exploitation, for instance the deep-sea mining of rare earth minerals that has only recently become technologically feasible.[86]

Advances in technology are altering the power balance of environmental governance by allowing new actors to enter the landscape and take impactful environmental actions. Decreasing costs and increasing availability of advanced technological tools is vastly expanding potential participation in environmental governance. This movement towards democratization characterizes use of emerging technology across sectors and is an important feature of the impacts that technology is having on environmental management, specifically. New actors are able to carry out new types of activities at scales and speeds never seen before, and this is challenging existing environmental regulation.

3. *Speed of Deployment*

Perhaps more than anything else, 4IR technologies are notable for the speed at which they are developed and deployed. Computer processing and storage capacity is increasing exponentially, changing the landscape of environmental technology over the span of weeks and months instead of years and decades.[87] New technological tools can be deployed extremely quickly, challenging existing regulatory structures to keep pace with these innovations.[88]

Velocity of innovation varies greatly among different actors. In general, the private sector is leading the charge in developing new environmental technologies.[89] This role in technology development, coupled with the fact that private sector actors tend to be more rapid adopters of technological advancements to begin with, means that corporate actors are for the most part much more rapid adopters of technology than the public sector. While private sector technology adoption is limited to areas that are relevant to corporate activities, these technologies are often ultimately repurposed by both public sector and nonprofit actors for environmental applications.

Not only is technology development increasing in speed, but it is also enabling faster interactions with the environment. New technologies can provide robust, real-time environmental data to managers, supporting better-informed management decisions and enabling more responsive management regimes.[90]

86. *See* Burton, *supra* note 57, at 1136–37; *A Lease is Granted for the First Ever Deep Sea Mining Project*, ECONOMIST INTEL. UNIT (Mar. 7, 2011), http://country.eiu.com/article.aspx?articleid=1687865153&Country=Papua%20New%20Guinea&topic=Econo_4.

87. Dave Owen, *Mapping, Modeling, and the Fragmentation of Environmental Law*, 2013 UTAH L. REV. 219, 244 (2013).

88. Marc A. Saner & Gary E. Marchant, *Proactive International Regulatory Cooperation for Governance of Emerging Technologies*, 55 JURIMETRICS 147, 149–50 (2015).

89. *See* Neri, *supra* note 45.

90. For a discussion of the impact that real-time data can have on enabling new management tools, *see* Sara M. Maxwell et al., *Dynamic Ocean Management Defining and Conceptualizing Real-Time Management of the Ocean*, 58 MARINE POL'Y 42, 43 (2015); Rebecca Lewison et al., *Dynamic Ocean*

Improvements in communication technologies enable information to be transmitted almost instantaneously from even the most remote areas.[91] The speed of this information flow is essential for more dynamic environmental management.

II. DEFINING ENVIRONMENTAL SILVER BULLETS

Emerging technologies are improving management capabilities throughout the environment. This Part describes how developments in the scale, accessibility, and speed of environmental technology are manifesting in practice, focusing on how different actors are incorporating technology into environmental governance. It shows that while technology is benefitting the public sector, it is having much more dramatic impacts for private actors who are better able to capitalize on the development of technology. These private sector actors are driving the rapid and often unregulated deployment of silver bullet technologies. This Part defines and characterizes these silver bullet technologies, then addresses theoretical issues that these technologies raise.

Environmental silver bullets are a subset of emerging technologies that seek to provide large-scale solutions to environmental problems. A true environmental silver bullet is a technological solution that aims to "fix" an environmental problem in one fell swoop.[92] Implicit in the cultural understanding of silver bullets is their impossibility: solutions that sound too good to be true usually are. Environmental silver bullets are nonetheless appealing and are often quick to generate public excitement. The following characteristics distinguish environmental silver bullets from other types of technologies: their aim to provide a technological fix to complex environmental problems, their ability to generate public support, and the impossibility of fully achieving their missions without other forms of intervention. Many environmental technologies share some characteristics with silver bullet technologies, but operate on a smaller scale and with narrower purposes. These technologies raise many of the same concerns about accountability and potential consequences, despite their smaller scale of environmental impacts. This Article considers both classic examples of silver bullets and emerging technologies that share silver bullet characteristics to understand how environmental governance regimes will need to adapt to accommodate them.

The search for silver bullets is not new. What is new is the effect concurrent advances in speed, scale, and accessibility of technology are having on these proposed solutions. The public for the first time can participate in the

Management Identifying the Critical Ingredients of Dynamic Approaches to Ocean Resource Management, 65 BIOSCIENCE 486, 488 (2015).

91. *See, e.g.*, LEAPE ET AL., *supra* note 16, at 4–5 (describing improvements in communication technology in deep ocean environments).

92. This builds on the broader definition of silver bullet, which according to the Oxford English Dictionary is "a simple and seemingly magical solution to a complicated problem." *Silver Bullet*, OXFORD ENG. DICTIONARY, https://www.oed.com/silver-bullet.

development and deployment of large-scale environmental silver bullet technologies. The resulting environmental consequences are largely beyond the reach of existing governance mechanisms that force full consideration of environmental tradeoffs and provide some measure of accountability.

The most notable examples of environmental silver bullets are those currently being proposed and deployed in attempts to mitigate climate change. These geoengineering solutions may ultimately be necessary to prevent catastrophic impacts of climate change, but the discourse to date has focused on their potential extensive negative impacts.

Geoengineering solutions are criticized not only for their negative impacts, but for concerns that counting on these technological fixes will prevent policy makers from taking other necessary mitigation measures, like reducing emissions.[93] This illustrates an important point about environmental silver bullets more broadly: while the concrete environmental consequences may be relatively easy to measure and address, they are not the only negative impacts of relying on technological solutions to environmental problems. Ignoring the systemic causes of environmental degradation undermines the effectiveness of technological interventions. Meanwhile, relying on technology to save the day diverts needed resources and momentum away from making necessary systemic changes.[94]

Environmental silver bullets address the spectrum of environmental issues beyond just climate change. From genetic interventions aimed at eradicating invasive species, to engineered meats that provide a less resource-intensive protein alternative, to advanced machine learning surveillance applied to environmental enforcement problems, emerging technologies are providing new hope for solving previously intractable environmental issues.[95]

A. Environmental Technology Adoption

Understanding the impacts of environmental silver bullets requires assessing how these silver bullets are being used and deployed by different actors. While promoters of silver bullet technologies tend to focus on the technologies themselves as solutions, these technologies are tools in larger societal systems.[96] How the risks and benefits of emerging technologies are

93. *See* Michael C. Branson, *A Green Herring How Current Ocean Fertilization Regulation Distracts from Geoengineering Research*, 54 SANTA CLARA L. REV. 163, 165 (2014) ("Many fear that a discussion on geoengineering, let alone basic research on the subject, will undermine the current emphasis on reducing carbon emissions.").

94. *See, e.g.*, Sheila Jasanoff, *The Dangerous Appeal of Tech*, MIT TECH. REV. 16, 17 (2021) (giving the example of this phenomenon in the US biomedicine industry, where "energy, attention, and money tend to be directed to high-impact, silver-bullet solutions, or 'moonshots,' rather than to messier changes in the social infrastructures that give rise to many health problems.").

95. *See, e.g.*, WORLD ECON. F., *supra* note 8, at 10 (describing various emerging technologies being leveraged for environmental outcomes).

96. *See* Ryan Calo, *The Scale and the Reactor* 5 (Apr. 9, 2022), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4079851 ("the path of technology cannot be fully anticipated in advance,

balanced will vary greatly depending on which actors are evaluating the tradeoffs. Who is deploying technologies defines the speed at which new technologies are adopted, as well as what degree of formal or informal accountability governs these projects. How these factors interact is critical in determining the impact environmental technologies will have on global ecosystems, for better or worse.

1. Technology in the Public Sector

Emerging technologies are potentially powerful tools for public agencies seeking to achieve environmental goals and enforce existing regulations. However, for the most part, rapidly emerging silver bullet technologies will not fundamentally reshape the missions or goals of environmental agencies.[97] They will improve existing processes and allow more efficient and effective management. Despite the promise of technology, government agencies are often slow and unwieldy in adopting emerging technologies.[98] Government technology adoption in practice shows that existing procedural requirements limit the public sector's ability to take advantage of the speed, scale, or access potential of new technologies.[99] At the same time, the accountability mechanisms built into public technology procurement and deployment processes work to ensure that technologies are fit for purpose and free of major unintended consequences.

Governments are adopting technology to support existing regulatory mandates and goals. In the case of environmental management, some of the most notable technological improvements are to the tools used to carry out public monitoring.[100] Baseline environmental data is critical for government agencies to understand and react to emerging environmental problems. In general, environmental regulation requires two types of data collection: targeted compliance monitoring of regulated facilities and ambient monitoring of baseline ecosystem data.[101] Compliance monitoring is used to determine whether regulated entities are meeting regulatory requirements and is often done in

and that the impacts of technology on society depend on the ways humans and institutions understand and use their tools.").

97. *See* Kelly, *supra* note 34, at 1139–40 (discussing the ways in which technological improvements impact management).

98. *See*, DARRELL M. WEST & JENNY LU, COMPARING TECHNOLOGY INNOVATION IN THE PRIVATE AND PUBLIC SECTORS 18 (2009) (discussing how public sector technology adoption lags behind the private sector); Melissa Garren et al., *How Performance Standards Could Support Innovation and Technology-Compatible Fisheries Management Frameworks in the U.S.*, 131 MARINE POL'Y 104, 631, 104, 631–32 (2021) (detailing barriers to government use of new technologies in fisheries enforcement).

99. *See* Ines Mergel, *Open Innovation in the Public Sector Drivers and Barriers for the Adoption of Challenge.gov*, 20 PUB. MGMT. REV. 726, 727 (2018) (describing the barriers to U.S. government adoption of innovative technology products).

100. *See* Esty, *supra* note 26, at 156–58; Biber, *supra* note 37, at 31–32.

101. *See* Biber, *supra* note 37, at 9–10.

partnership with industry.[102] Ambient monitoring collects broad information on environmental conditions, a core function of federal environmental agencies, but unfortunately a function that agencies have struggled to meet.[103] Emerging technologies hold opportunities to dramatically improve both types of public environmental monitoring.

Ambient environmental data is the bedrock of effective environmental regulation, but its collection is difficult and resource intensive.[104] Data must be collected frequently enough that it provides robust baseline information and shows deviations from those conditions.[105] Data also must be at fine enough spatial scales that it can capture the high heterogeneity inherent across national ecosystems. EPA and other agencies have generally lacked the resources to meet the burden created by regulatory monitoring requirements.[106] Emerging technologies have the potential to mitigate this challenge by dramatically improving existing ambient environmental monitoring. At base, the cost of sensors has dropped precipitously, creating much more economical avenues for obtaining data.[107] Data transmission and storage capabilities are also less expensive and more efficient than ever before. This allows large volumes of data to be transferred from field monitoring locations and stored in large cloud-based datasets.[108] Advanced machine learning algorithms can process large datasets and generate new insights about environmental conditions. Spatial mapping and modeling tools can provide a more holistic understanding of cumulative ecosystem impacts.[109] Taken together, these advances in monitoring open new doors for agencies to understand environmental conditions nationally and internationally.[110]

Compliance monitoring is also benefitting from improved technologies. In the US, compliance monitoring is carried out both by EPA and by regulated industries, which are required to actively monitor and report on compliance with pollution discharge limits and other legal requirements.[111] The same improvements in low-cost sensors and spatial modeling that are fueling advances

102. *See* Robert L. Glicksman et al., *Technological Innovation, Data Analytics, and Environmental Enforcement*, 44 ECOLOGY L. Q. 41, 69–71 (2017).

103. *See* Biber, *supra* note 37, at 14.

104. *Id.* at 14, 31–32.

105. Owen, *supra* note 87.

106. *See* Oliver A. Houck, *The Clean Water Act Returns (Again) Part I, TMDLs and the Chesapeake Bay*, 41 ENV'T L. REP. 10,208, 10,212 (2011) (discussing how only 1/3 of the waters that the Clean Water Act mandates EPA to monitor are assessed, while those that are monitored are often only monitored a couple of times a year, far too infrequently to provide a robust basis for decision-making).

107. *See* Annie Brett et al., *Ocean Data Need a Sea Change to Help Navigate the Warming World*, 582 NATURE 181, 181 (2020); Ron Miller, *Cheaper Sensors Will Fuel the Age of Smart Everything*, TECHCRUNCH (Mar. 10, 2015), https://techcrunch.com/2015/03/10/cheaper-sensors-will-fuel-the-age-of-smart-everything/.

108. *NOAA Expands Public Access to Big Data*, NAT'L CTRS. FOR ENV'T INFO., NOAA (Dec. 10, 2018), https://www.ncei.noaa.gov/news/noaa-expands-big-data-access.

109. Owen, *supra* note 87, at 223.

110. Esty, *supra* note 26, at 156–60.

111. *See* Biber, *supra* note 37, at 9–12.

in ambient monitoring also benefit compliance monitoring.[112] It is easier and more cost-effective than ever before for government agencies to monitor at fine spatial and temporal scales, allowing agencies to specifically target locations near large industrial facilities to ensure that pollution discharges meet regulatory targets.

New technologies can also provide more comprehensive monitoring in areas where this was previously limited by practical constraints. The fishing industry, for example, historically has been difficult to monitor as fishing vessels operate far from shore for extended periods of time.[113] Regulators have dealt with this in various ways, including by mandating that fishing vessels carry government observers onboard to ensure compliance with fishing laws.[114] However, the observer program is costly and riddled with harassment and abuse of observers.[115] As a result, observer coverage is usually only mandated on a small percentage of all vessel trips, easily allowing fishermen to break the law when they are not being observed.[116] New video-based surveillance tools for fishing vessels are changing the existing paradigm.[117] Strategically placed cameras onboard fishing vessels can film crews fishing, capturing not only when and where fishing is taking place, but also rough estimates of the amount and types of fish being brought onboard.[118] These cameras have the potential to replace the need for human observers and offer low-cost surveillance of not just some, but all vessels fishing in US waters, dramatically increasing compliance monitoring coverage. Similar improvements in compliance monitoring are happening throughout environmental industries nationally.[119]

Monitoring is not the only area where technology is helping to improve public environmental governance. Emerging technologies are also being adopted for efforts to remediate and restore degraded ecosystems, to develop new genetic

112. Glicksman et al., *supra* note 102, at 71–72.

113. Read D. Porter, *Fisheries observers as enforcement assets Lessons from the North Pacific*, 34 MARINE POLICY 583, 583 (2010).

114. Garren et al., *supra* note 98, at 104, 635–36.

115. *See Evaluating Opportunities to Improve Prevention and Response of Sexual Assault and Sexual Harassment at the National Oceanic and Atmospheric Administration Oversight Hearing Before the Subcomm. on Oversight and Investigations to the H. Comm. on Nat. Res.*, 116th Cong. 33 (2020).

116. Read D. Porter, *Fisheries observers as enforcement assets Lessons from the North Pacific*, 34 MARINE POLICY 583 (2010) (discussing changes in fishing behavior when observers are not present); Christopher Ewell et al., *An evaluation of Regional Fisheries Management Organization at-sea compliance monitoring and observer programs*, 115 MARINE POLICY 103842, 103486 (2020) (noting numbers of fisheries globally with observer coverage).

117. KATIE WESTFALL ET AL., ENV'T DEF. FUND, ELECTRONIC TECHNOLOGIES AND DATA POLICY FOR U.S. FISHERIES: KEY TOPICS, BARRIERS, AND OPPORTUNITIES 1–3 (2020).

118. *Id.* at 3.

119. *See, e.g.*, *id.* at 1; Yin et al., *supra* note 42 (discussing agriculture); Babich, *supra* note 65, at 601–03 (discussing air quality); Kelly, *supra* note 34, at 1113–16 (discussing environmental management); Karen E.C. Levy, *The Contexts of Control Information, Power, and Truck-Driving Work*, 31 INFO. SOC'Y 160, 160–61 (2015) (discussing transportation).

approaches to disease vector mitigation, and others.[120] These technologies are offering new avenues to tackle some of the thorniest environmental challenges. For instance, large-scale environmental remediation has been very difficult and limited to relatively small areas.[121] Remediating climate change, for instance, would require removing greenhouse gases from the atmosphere on a global scale. Scientists and engineers are beginning to propose technological solutions for this, but they have yet to be implemented.[122]

While technological improvements hold remarkable promise for government agencies, public actors are notoriously slow to integrate new tools.[123] Required accountability processes also lead to slower adoption of emerging technologies. Moreover, government environmental agencies often lack the funds to procure the latest technological innovations. The governmental market for emerging environmental technologies remains relatively small, and budgets are tight.[124] The result is that technological advancements are driven in other fields and repurposed for environmental uses. These technologies are mostly developed by private sector actors and then bought and used by government agencies.[125] Some government funding does go into incentivizing the creation of environmental monitoring technologies, either through existing mechanisms like the National Science Foundation Small Business Innovation Research Fund or through government contracts, but these mechanisms do not inherently lead to technology adoption by government agencies.[126]

Significant accountability demands coupled with relatively slow technology adoption speeds mean that public environmental technologies are for the most part well-regulated when they are deployed, relative to technologies deployed by private actors. Moreover, when governments deploy technologies, they generally

120. *See, e.g.*, Sonya Ziaja, *How Algorithm-Assisted Decision Making Is Influencing Environmental Law and Climate Adaptation*, 48 ECOLOGY L. Q. 899 (2022); Emily Waltz, *First Genetically Modified Mosquitoes Released in the United States*, 593 NATURE 175, 175–76 (2021).

121. Timpane-Padgham et al., *supra* note 47.

122. *See, e.g.*, NAT'L. ACADS. SCI., ENG'G, MED., REFLECTING SUNLIGHT: RECOMMENDATIONS FOR SOLAR GEOENGINEERING RESEARCH AND RESEARCH GOVERNANCE (2021), https://nap.nationalacademies.org/catalog/25762/reflecting-sunlight-recommendations-for-solar-geoengineering-research-and-research-governance.

123. *See, e.g.*, F. Rizal Batubara et al., *Challenges of Blockchain Technology Adoption for E-Government A Systematic Literature Review*, PROC. 19TH ANN. INT'L CONF. ON DIGIT. GOV'T. RSCH. 1 (2018).

124. *See, e.g.*, NAT'L. ACADS. SCI., ENG'G, MED., LEVERAGING UNMANNED SYSTEMS FOR COAST GUARD MISSIONS: A STRATEGIC IMPERATIVE 2–4 (2020) (describing how the U.S. Coast Guard intends to be a "fast follower" in adoption of emerging autonomous monitoring technologies because they are unable to fund development of new technologies themselves).

125. *See e.g. See* NAT'L ACADS. SCI., ENG'G, & MED., LEVERAGING UNMANNED SYSTEMS FOR COAST GUARD MISSIONS 1, (2020) (describing the Coast Guard's approach of being a "fast follower" in adoption of emerging autonomous technologies for its missions, including environmental enforcement).

126. *See* Press Release, EPA, EPA Announces Over $3 Million in Funding to Small Businesses to Develop Environmental Technologies (Dec. 14, 2021), https://www.epa.gov/newsreleases/epa-announces-over-3-million-funding-small-businesses-develop-environmental (describing the recipients of EPA's latest SBIR funding round, intended to develop commercially viable environmental technologies).

do so in service to overarching regulatory missions that largely remain unchanged. Together, this means that, while emerging technologies are an important tool for public agencies, they are unlikely to fundamentally reshape how environmental agencies operate or rework their overarching missions.[127] The structural realities of government agencies make them ill-equipped to make the most of 4IR technologies in their own operations, as they are limited in both speed and scale of deployment by administrative procedures and goals.[128] This is perhaps a positive and intentional feature of government action, trading speed and scale for high levels of accountability and reliability. However, it also means that much of the transformative action around environmental technology is not happening in the public sector.

2. Technology in the Private Sector

Unlike the public sector, the private sector is well-equipped to take advantage of the revolutionary capabilities of 4IR technologies to achieve environmental goals. The private sector is spearheading the development of new, sophisticated technologies for environmental management, with diverse actors rapidly deploying large-scale 4IR technologies that are challenging existing regulatory structures and providing new avenues for environmental action.[129] In some cases, these are efforts to mitigate public institutional failures by providing new solutions.[130] In others, technology allows for new commercial opportunities in the environment.

From corporations to nonprofits to individuals, technology is enabling private actors to engage in environmental governance in increasingly prominent ways. These actors tend to adopt technological advancements much more rapidly than the public sector and are subject to significantly fewer accountability mechanisms.[131] Technology is pioneering new opportunities to participate in environmental governance and increasing transparency, but it is particularly opening doors for the wealthiest group of citizens. While technology has the potential to improve accessibility and participation in environmental decision-making, in practice, advancements often further consolidate power in the hands of those who already have it.[132] Initial indications suggest that the world of

127. Unless you view information age advances in monitoring as a paradigm shift in and of themselves. *See* LINDA BREGGIN & JUDITH AMSALEM, ENV'T L. INST., BIG DATA AND ENVIRONMENTAL PROTECTION: AN INITIAL SURVEY OF PUBLIC AND PRIVATE INITIATIVES 3 (2014); Gregg P. Macey, *The Architecture of Ignorance*, 6 UTAH L. REV. 1627, 1630–31 (2013).

128. *See, e.g.*, MCGUINNESS & SCHANK, *supra* note 6, at 1–18 (providing examples of how federal agencies carry out technology adoption).

129. *See* WORLD ECON. F., *supra* note 36 at 9–11.

130. *See* MCGUINNESS & SCHANK, *supra* note 6, at 68–71 (describing technology based solutions to government failures).

131. *See id*. at 13–16 (discussing constraints to rapid technology adoption in the public sector).

132. *See id*. at 57–73.

environmental technology is following this precedent.[133] Despite the promise, significant resources need to be expended to develop technologies in ways that make them accessible to those without technical expertise. While corporate actors garner much of the academic and policy attention for their role in environmental governance, individuals and philanthropists are using new technology to impact environmental outcomes, too.

a. Corporations

Private environmental governance is an increasingly important part of environmental management.[134] While private actors were important players in environmental law in the early twentieth century, in what some have called the "first stage" of environmentalism, this prominence diminished significantly after the passage of major federal environmental legislation in the 1970s. That legislation solidified government agencies as the primary actors in environmental governance.[135]

Recently though, the importance of private actors in environmental governance is once again increasing. The International Institute for Sustainable Development, for instance, recognizes a broad shift from the private sector primarily causing environmental harms to now working as "genuine partners and transformers supporting sustainable development or driving systems change."[136] Academics led by Michael Vandenbergh have dubbed this private environmental governance (PEG).[137]

The PEG literature focuses primarily on the role of corporations in carrying out myriad environmental functions, with efforts spanning the scope of traditional government regulation.[138] In some cases, private governance efforts work directly to influence and shape public environmental regulation, while in others private actors create their own forms of environmental governance.[139] Private companies engage in many different types of governance, from standard setting to self-policing.[140] The importance of these private entities in shaping environmental outcomes, not just through advocacy but also through direct action, has increased dramatically in recent years, in part because of government failures to effectively mitigate complex environmental problems.

133. *See generally* Ziaja, *supra* note 120 (analyzing how algorithmic decision-making can be in tension with transparency, accountability, equity, and broad stakeholder participation).

134. Vandenbergh, *supra* note 19, at 134.

135. Galperin, *supra* note 19, at 53.

136. DINA HESTAD, INT'L INST. FOR SUSTAINABLE DEV., THE EVOLUTION OF PRIVATE SECTOR ACTION IN SUSTAINABLE DEVELOPMENT 1 (2021).

137. Vandenbergh, *supra* note 19.

138. *Id.* at 133 (noting that "new private environmental governance activities play the standard-setting, implementation, monitoring, enforcement, and adjudication roles traditionally played by public regulatory regimes").

139. *See id.* at 170–73.

140. *Id.* at 133, 173.

Some themes unite traditional corporate PEG action and distinguish it from action by other types of private entities. First, corporate environmental activities tend to be closely tied to existing company activities. Fishing companies, for instance, work together to create voluntary sustainability and traceability standards for seafood.[141] Plastic companies sponsor international collaboration to reduce and remediate plastic pollution.[142] These efforts are often more efficient for companies to undertake than for governments because companies already operating in the space have the knowledge and infrastructure needed to easily tackle these challenges.[143]

Corporations also frequently engage in bilateral or multilateral PEG efforts. For instance, Walmart, one of the early PEG movers and the subject of early PEG literature, works in concert with other corporations, nonprofits, and governments to achieve their PEG goals.[144] The rise of public-private partnerships also illustrates the coalition-building tendency of corporate PEG activity.[145] Major national and international partnerships between large corporations and governments are reshaping global environmental agendas.[146] From solutions for mitigating plastic pollution, to reforesting, to reducing fossil fuel emissions, public-private partnerships are tackling some of the thorniest issues in environmental policy.[147] Many academics and policymakers believe that these types of partnerships offer new opportunities to make progress on previously intractable issues.

For-profit companies seeking to develop environmental technologies face several challenges.[148] In some areas, the government is a large player in driving technological innovation, for example providing incentives for developing renewable energy technologies, and thereby driving significant private sector engagement.[149] In other cases, companies developing environmental technologies ultimately plan to market them to government agencies and, therefore, are very responsive to government demand. For instance, companies are developing sophisticated robots to map the ocean floor, clean up oil spills, or

141. *See, e.g.*, *About the Global Dialogue*, GLOB. DIALOGUE ON SEAFOOD TRACEABILITY, https://traceability-dialogue.org/what-is-the-global-dialogue/ (last visited Dec. 15, 2022).

142. *About Us*, GLOB. PLASTIC ACTION P'SHIP, https://globalplasticaction.org/about/ (last visited Dec. 15, 2022).

143. M. Todd Henderson & Anup Malani, *Corporate Philanthropy and the Market for Altruism*, 109 COLUM. L. REV. 571, 590–603 (2009).

144. *See* Michael P. Vandenbergh, *The New Wal-Mart Effect The Role of Private Contracting in Global Governance*, 54 UCLA L. REV. 913, 918 n.14, 927 (2007).

145. Liliana B. Andonova, *Public-Private Partnerships for the Earth Politics and Patterns of Hybrid Authority in the Multilateral System*, 10 GLOB. ENV'T POL. 25, 25–26 (2010).

146. *Id.*

147. *See, e.g.*, Axel Marx, *Public-Private Partnerships for Sustainable Development Exploring Their Design and Its Impact on Effectiveness*, 11 SUSTAINABILITY 1087 (2019) (providing an overview of public-private partnership operations).

148. Söderholm, *supra* note 27, at 4–5.

149. *Id.* at 6–7.

police protected areas in response to government interest.[150] In both of these cases, the types of technologies that are developed are limited in their substantive application to areas the government is interested in, permitting certain large, well-connected, companies to take advantage of the government market. Technologies developed by corporations to be used in-house, such as those that increase efficiency and profits, are similarly limited in their substantive application.[151] This limits the landscape of corporate technologies: private sector technological participation only occurs where there is a market.

b. Nonprofits

Beyond corporations, nonprofits are also powerful private shapers of environmental regulatory outcomes.[152] Their importance is increasing in areas traditionally reserved for government action, like enforcement of environmental laws, where government action has been insufficient in the face of increasing environmental pressures.[153] Environmental NGOs bring much of the environmental litigation in the US, for instance, where over three quarters of climate change litigation is filed by NGO plaintiffs.[154] NGOs play important roles in creating and enacting regulation, with teams of lobbyists targeting Congress and EPA.[155] Significant areas of land are owned and conserved by NGOs.[156] NGOs also carry out direct action to improve environmental conditions. Technological advances are helping nonprofits in all these areas, often in similar ways to other public and private sector actors.

Despite the important role NGOs play in environmental law, relatively little legal literature is devoted to their place in the PEG landscape. Michael

150. *See, e.g.*, *Saildrone Ramps Up Maritime Security Capabilities with Key Hires from Navy, Coast Guard*, SAILDRONE (Sept. 1, 2021), https://www.saildrone.com/news/cameron-mccord-bob-kelly-join-saildrone-expand-maritime-security (describing Saildrone's defense capabilities for government partners); Martin Kahl, *How Autonomous Technology Helps Tackle the Monumental Task of Mapping the Seabed*, GROUND TRUTH (Nov. 5, 2021), https://groundtruthautonomy.com/robotics/how-autonomous-technology-helps-tackle-the-monumental-task-of-mapping-the-seabed/ (discussing new companies Terradepth and Bedrock are marketing autonomous vessel solutions for global government seabed mapping initiatives).

151. *See, e.g.*, DELOITTE, *supra* note 46.

152. Kal Raustiala, *The "Participatory Revolution" in International Environmental Law*, 21 HARV. ENV'T L. REV. 537, 540 (1997) ("States have come to rely upon particular NGOs within environmental law because it is politically and technocratically beneficial for them to do so . . .").

153. LINDA A. MALONE & SCOTT PASTERNACK, DEFENDING THE ENVIRONMENT: CIVIL SOCIETY STRATEGIES TO ENFORCE INTERNATIONAL ENVIRONMENTAL LAW 289 (2006) ("It is no longer correct to conclude that enforcement is the province of nation-states, with civil society as merely the third-party. . . Individuals, community groups, NGOs, and international organizations have a pivotal role in monitoring and enforcement of the established and emerging norms . . .").

154. David Markell & J. B. Ruhl, *An Empirical Survey of Climate Change Litigation in the United States*, 40 Env't L. Rep. (Env't Law Inst.) 10,644, 10,649 (2010).

155. *See* Robert V. Percival, *Environmental Legislation and the Problem of Collective Action*, 9 DUKE ENV'T L. POL'Y F. 9, 19 (1998).

156. Lee P. Breckenridge, *Nonprofit Environmental Organizations and the Restructuring of Institutions for Ecosystem Management*, 25 ECOLOGY L. Q. 692, 694 (1999).

Vandenbergh briefly acknowledges that NGOs are important players in his foundational writing on PEG.[157] Joshua Galperin builds on this to illustrate different approaches of environmental NGOs and to suggest a typology for defining NGO participation in PEG.[158] Galperin describes the interaction of NGOs with corporate actors as an important defining component of the role NGOs play in PEG.[159] Other work by Andrew Hoffman has similarly found that the role of environmental NGOs is defined by their relationships to corporations.[160]

4IR technology advances are improving what nonprofits can achieve in their environmental work.[161] Scholars of philanthropy have distinguished between efforts to influence outcomes by changing the attitudes of key players or the public at large, versus efforts to directly change conditions on the ground through active interventions.[162] Some of the most important ways nonprofits influence outcomes is through monitoring environmental conditions. Large international nonprofits are important funders of scientific monitoring programs across the globe, collecting critical datasets that governments are unable to fund.[163] Smaller, local nonprofits also provide important environmental data, generally collecting data on the hyperlocal scales necessary to identify certain environmental problems.[164] Both of these types of nonprofits feed this information back to governments in formal and informal ways.[165] Currently, some of the most robust information on environmental baselines is collected by nonprofits and contributed to government databases to help meet government monitoring mandates.[166]

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157. *See* Vandenbergh, *supra* note 19, at 170.

158. Joshua Ulan Galperin, *Board Rooms and Jail Cells—Assessing NGO Approaches to Private Environmental Governance*, 71 ARK. L. REV. 403, 423–64 (2018).

159. *Id*. at 404–06 (describing The Nature Conservancy as "corporate-consensus-oriented" in contrast to Greenpeace's "corporate-conflict orientation").

160. *See* Andrew J. Hoffman, *Shades of Green*, STAN. SOC. INNOVATION REV. 40, 40 (2009) (dividing environmental NGOs into two groups: "one that partners with business and the other that doesn't.").

161. *Id*. ("We must understand NGOs vis-à-vis their corporate targets and partners, as independent agents who promote certain legal instruments, as participants in a robust network of influencers and actors, and, more subtly, as story tellers.").

162. John J. Chung, *Rethinking the Role of NGOs in an Era of Extreme Wealth Inequality The Example of the Bill & Melinda Gates Foundation*, 26 ROGER WILLIAMS U. L. REV. 1, 10–11 (2021).

163. *See* Linda K. Breggin & Judith Amsalem, *Big Data and the Environment A Survey of Initiatives and Observations Moving Forward*, 44 Env't L. Rep. (Env't Law Inst.) 10,984, 10,991 (2014).

164. *See* Finn Danielsen et al., *Local Participation in Natural Resource Monitoring A Characterization of Approaches*, 23 CONSERVATION BIOLOGY 31, 31–42 (2009) (overviewing the various approaches and varying degrees of local participation in data collection).

165. *See, e.g.*, Abby J. Kinchy et al., *What is Volunteer Water Monitoring Good For? Fracking and the Plural Logics of Participatory Science*, 27 POL. POWER & SOC. THEORY 259, 273 (2014); Abby J. Kinchy & Simona L. Perry, *Can Volunteers Pick up the Slack? Efforts to Remedy Knowledge Gaps About the Watershed Impacts of Marcellus Shale Gas Development*, 22 DUKE ENV'T L. POL'Y F. 303, 325–26 (2012).

166. *See* William V. Luneburg, *Where the Three Rivers Converge Unassessed Waters and the Future of EPA's TMDL Program—A Case Study*, 24 J. L. COM. 57, 67 (2004).

Technology is also improving nonprofits' ability to publish this data for the public in ways that are cost-effective and accessible. Because nonprofit funding is so tightly tied to public donations, NGO information dissemination is generally much more successful than efforts by the federal government because it is a priority for NGOs that rely on well-communicated information to spur additional donations.[167] Government environmental agencies do work to publicize certain types of environmental data for untrained members of the public. However, these efforts are usually restricted to specific environmental datasets and often are not allocated sufficient resources to be truly successful.[168] Nonprofits make information dissemination a more integral focus of their organizations, providing critical environmental information to the public in formats that are often more digestible than data disseminated by the government.[169]

Beyond raising awareness, environmental nonprofits lead the way in restoration and conservation projects globally.[170] Nonprofits are often less tied to Congressional environmental mandates than government agencies or large corporations, so they can cast a wide net in working to address and remediate environmental degradation. This was a core function of environmental nonprofits when they first came to prominence in the middle of the twentieth century, and it has remained one of the most important and impactful aspects of their operations.[171] Technology is aiding this trend, particularly driven by a suite of companies focused on creating low-cost environmental technologies tailored specifically for NGOs.[172]

NGO adoption of emerging technologies is often limited by available resources. Like public agencies, NGO have tight budgets and finite resources. Adoption is slowed by the reality that technologies are generally developed first by private sector actors and usually go through multiple iterations before they are available to the NGO community. NGO funding timelines limit the speed of adoption as well, because they have longer time horizons between initial project conception and implementation than the private sector.

c. Individuals

If nonprofits have been relatively overlooked in the PEG literature, the role of private individuals in environmental governance has received even less scrutiny. Expanding access to environmental governance is a core feature of 4IR technologies. Low-cost technologies are opening new avenues for public

167. *See, e.g.*, David V. Budescu et al., *Improving Communication of Uncertainty in the Reports of the Intergovernmental Panel on Climate Change.*, 20 PSYCH. SCI. 299 (2009).

168. *See* Linwood H. Pendleton et al., *Disrupting Data Sharing for a Healthier Ocean*, 76 ICES J. MARINE SCI. 1415, 1415–23 (2019).

169. *See, e.g.*, Galperin, *supra* note 158, at 435–38, 445–51.

170. *Id.*

171. *See id.* at 404–06, 428–61.

172. *See, e.g.*, *About*, FIELDKIT, www.fieldkit.org/about (last visited Dec. 15, 2022).

engagement with environmental management,[173] helping tackle complex environmental problems while also providing more equitable access and solutions.[174] However, ensuring technologies lead to greater participation is not so easy.

Our current era is not the first in which major technological advances have promised to broaden participation in improving environmental conditions. Reviewing history shows more mixed outcomes than much of the rhetoric around technology and democratization might suggest. For instance, during the Third Industrial Revolution, many were excited by the potential for the internet and other new technologies to help solve environmental problems and improve public access to environmental information.[175] There has been mixed success in fulfilling these promises, though. The internet has been a true revolution, opening new avenues for participation to the public. But, the systems that have been built still do not achieve most of their public engagement goals.[176] Technology advances systematically disadvantage certain groups and exclude them from participation in environmental governance.[177] Moreover, much of the infrastructure on which the Third Industrial Revolution is built has worsened environmental problems.[178] The Fourth Industrial Revolution may be following in this path. Despite the theoretical promise of emerging technologies and the grand rhetoric public officials offer in their support, technology advances now are leading to worse environmental outcomes and are not yet living up to their participatory potential.

The impact of 4IR technologies in enabling individual engagement highlights this: while new technologies have expanded how members of the public can engage with environmental governance, as described in Part I, they have provided significantly more impactful opportunities for the wealthiest individuals. Technology is enabling a class of billionaires to have exponentially greater impacts on environmental outcomes, giving them the power not only to shape the global landscape of environmental policy, but also to carry out their own projects to directly alter environmental conditions.[179] In this way, 4IR environmental technologies help to solidify existing social hierarchies and reflect broader societal trends towards inequality.

173. *See infra* Part I.

174. *See* Wesselink et al., *supra* note 71 (providing more information about public participation and stakeholder engagement's design forms and policy rationales).

175. *See* SCHWAB, *supra* note 23.

176. *See, e.g.*, Esty, *supra* note 26 (discussing the flaws with existing technological methods for public participation).

177. *See, e.g.*, Jason Corburn, *Bringing Local Knowledge into Environmental Decision Making*, 22 J. PLAN. EDUC. & RSCH. 420 (2003).

178. *See, e.g.*, Jeff A. Ardron et al., *Incorporating Transparency into the Governance of Deep-Seabed Mining in the Area Beyond National Jurisdiction*, 89 MARINE POL'Y 58, 58 (2018) (discussing battery demand driving mining in fragile ecosystems).

179. ROB REICH, JUST GIVING: WHY PHILANTHROPY IS FAILING DEMOCRACY AND HOW IT CAN DO BETTER 152 (2019) (discussing "a particular kind of high-profile philanthropist . . . whose activity supplants the state, subverts public policy processes, and in doing so diminishes democracy.").

As one example, Mark Benioff, the billionaire founder of the software company Salesforce, has had an outsized role in determining global environmental agendas over the past five years by donating hundreds of millions to fund major ocean and forestry initiatives.[180] These include establishing a project to plant one trillion trees and creating the Friends of Ocean Action, a group including former heads of state and other ocean policy leaders that aims to directly influence global ocean policy.[181] Benioff's role in these initiatives has quickly established him as a major player in global environmental outcomes. He sees CEOs and other wealthy actors as critical players in saving the world, going so far as to call them "heroes" for their role in addressing global crises like COVID.[182] Beyond Benioff, other similarly wealthy individuals are driving environmental policy across the globe, reshaping policy agendas, driving new environmental laws, and creating coalitions that rival large-scale international organizations in their influence.[183]

Private philanthropists have also become some of the largest funders of global environmental science agendas. This is particularly true in the area of oceans, where research is notoriously expensive and difficult.[184] American billionaire Ray Dalio launched OceanXplorer in 2020 as the largest and most technologically advanced research vessel ever built.[185] Norwegian billionaire Kjell Inge Røkke is in the process of building an even larger vessel to conduct groundbreaking scientific research.[186] Eric and Wendy Schmidt, of Google wealth, use their foundation to run an oceanographic research vessel.[187] These individuals have stepped in to provide additional funding for critical scientific research that current governments are not able to provide, thereby improving global understanding of environmental conditions. However, this structure also gives these wealthy individuals an outsized role in dictating what environmental

180. *See, e.g.*, *Marc and Lynne Benioff, Salesforce Announce $300 Million in Investments to Accelerate Ecosystem Restoration and Climate Justice*, SALESFORCE (Oct. 28, 2021), https://www.salesforce.com/news/press-releases/2021/10/28/marc-and-lynne-benioff-and-salesforce-announce-investment-to-accelerate-ecosystem-restoration-and-climate-justice (last visited Dec. 15, 2022).

181. *Who We Are*, FRIENDS OF OCEAN ACTION, https://www.weforum.org/friends-of-ocean-action/who-we-are.

182. Peter S. Goodman, *C.E.O.s Were Our Heroes, at Least According to Them*, N.Y. TIMES (Jan. 16, 2022), https://www.nytimes.com/2022/01/13/business/davos-man-marc-benioff-book.html ("'In the pandemic, it was C.E.O.s in many, many cases all over the world who were the heroes,' Mr. Benioff said. 'They're the ones who stepped forward with their financial resources, their corporate resources, their employees, their factories, and pivoted rapidly—not for profit, but to save the world.'").

183. REICH, *supra* note 179, at 151–52.

184. *See e.g.* Ian Evans, *Solving the Sky-High Costs of Ocean Exploration with A.I.* New Humanitarian (Feb. 9, 2018), https://deeply.thenewhumanitarian.org/oceans/community/2018/02/09/solving-the-sky-high-costs-of-ocean-exploration-with-a-i.

185. *See* William J. Broad, *A New Ship's Mission Let the Deep Sea Be Seen*, N.Y. TIMES (Sept. 17, 2020), https://www.nytimes.com/2020/09/17/science/ocean-exploration-dalio-ship.html.

186. *See generally* REV OCEAN, https://www.revocean.org/ (last visited Dec. 22, 2022).

187. *Our Story*, SCHMIDT OCEAN INST., https://schmidtocean.org/about/our-story/ (last visited Dec. 22, 2022).

data is available and how it is used by decision-makers. Instead of government agencies like NSF or NOAA determining what research projects are worth funding, now idiosyncratic billionaires are doing so. The research that gets funded and supported thus may reflect a fundamentally different set of values, less oriented toward overall public welfare and instead reflecting the priorities of a few. Privatizing basic environmental research has major implications for the future of environmental governance and knowledge, globally.[188]

Beyond influencing research, wealthy individuals prominently champion silver bullet technologies, arguing that they will help to solve some of the largest environmental problems of the day. Private philanthropists are generally more willing to fund ambitious, large-scale projects than government actors.[189] For instance, The Ocean Cleanup, which markets itself as "the largest cleanup in history" and aims to "rid the oceans of plastic," has primarily benefitted from the wealth of billionaire Mark Benioff.[190] Similar conservation projects, including ocean iron fertilization, 3D printed horns for rhinos, and genetic preservation and revival of extinct species, are being funded and pioneered by a new breed of wealthy philanthropists.[191] These projects are novel for their scope, which is technologically enabled, as well as for their focus on providing public goods by remedying large-scale environmental harms.

Less flashy, more complex, necessary technologies have a much more difficult time getting funded, leading to the moniker "tough tech."[192] Philanthropic activities are less focused on carrying out monitoring tasks and more focused on restoration, conservation, and environmental improvement projects. The potential for disruptive change is larger in these areas, and most of the public sees these crises as more meaningful to engage in. Wealthy individuals seeking to make a mark on the world, either to improve their public image or out of genuinely altruistic interests, are more likely to engage in technological endeavors that aim to actively change environmental conditions than to invest in complex but vitally important monitoring efforts or smaller-scale projects that could still have a positive impact on the environment.

Developing environmental technologies fits within the general model of philanthropic amateurism, which, as Erik Amarante puts it, "stems from the illogical belief that wealthy individuals are equipped to address some of the world's most complex and intransigent problems simply because they

188. *See* Hoy, *supra* note 4.

189. *Id.* (noting that "Very ambitious projects are unlikely to get through the federal screening process. Philanthropists, on the other hand, are comfortable with longer term investments, and investments without a specific application in mind, for higher potential return.").

190. *See* THE OCEAN CLEANUP, *supra* note 12; Jennifer Kahn, *Mark Benioff Bets on Cleanup Tech for Ocean Trash*, WIRED (Sept. 18, 2018), https://www.wired.com/story/wired25-marc-benioff-boyan-slat-ocean-cleanup-plastic/.

191. *See infra* Part III(B).

192. *See* Katherine Ellison, *Philanthropies Flow Funds to Climate Technologies*, WASH. POST (Oct. 14, 2020), https://www.washingtonpost.com/climate-solutions/2020/10/14/climate-change-philanthropy/.

successfully amassed a fortune in the private sector."[193] In the case of environmental technologies, this belief seems to be even more extreme when those wealthy individuals have amassed their wealth through technology ventures. The familiarity with technology generally leads philanthropists both to focus on technology as a solution to environmental problems and to believe that they are uniquely well-suited to create these solutions.[194]

All these private actors, corporations, nonprofits, and individuals are taking on important new roles in environmental governance that are made possible by new types of technology. This paradigm shift deemphasizes government action and puts considerably more power in the hands of private actors. Wealthy individuals are becoming an increasingly important and influential part of environmental governance globally, enabled by a new era of technology.

B. Theoretical Considerations for Environmental Technologies

The rapid adoption of large-scale technology solutions for wicked environmental problems raises concerns about the risks associated with these technologies, how existing governance regimes will apply to their emerging uses, and what mechanisms are in place to ensure transparency and accountability. That private sector actors are in most cases driving the deployment of large-scale interventions deepens many of these concerns: while risk mitigation, accountability, and transparency are baked into public sector processes, this often is not the case in the private sector.

1. Governance

Whether existing regulation will apply to 4IR technologies and the ways that they are being used to achieve environmental ends varies across the legal landscape. However, in nearly all cases, these technologies will present challenges to existing regulatory frameworks. New technologies are being used in ways that generally were not contemplated when major environmental laws and regulations were passed. The result is that existing environmental laws often do not adequately address proposed silver bullet activities.[195]

Governance gaps have been created not only by technologies enabling new types of activities, but also by private actors engaging in environmental

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193. Eric Franklin Amarante, *The Perils of Philanthrocapitalism*, 78 Md. L. Rev. 1, 1 (2018).

194. This is not just the case with wealthy individuals; many have noted the phenomenon of tech "bros" becoming interested in climate change issues and believing that their expertise will allow them to make game-changing contributions to the field. This isn't usually how things play out, and the belief that technological innovation will solve climate change and other complex environmental problems has been dubbed the "engineer's myth." *See* MICHAEL P. VANDENBERGH & JONATHAN M. GILLIGAN, BEYOND POLITICS: THE PRIVATE GOVERNANCE RESPONSE TO CLIMATE CHANGE 129 (2017); DAVID G. VICTOR, GLOBAL WARMING GRIDLOCK: CREATING MORE EFFECTIVE STRATEGIES FOR PROTECTING THE PLANET 31–32 (2011).

195. For a more in-depth discussion of the governance gaps created by existing environmental laws, see the case studies in Part III.

governance in new ways. Vandenbergh makes a distinction between private actors engaging in traditional government functions and acting with traditional government objectives.[196] The primary mechanism for private environmental governance has been private actors taking on traditional government functions and engaging in quasi-regulatory activities, like creating standards.[197] 4IR technologies, however, are increasingly allowing private actors to participate in traditional government activities, like improving environmental conditions through remediation projects.[198]

In working on projects intended to provide environmental public goods, private actors increasingly find themselves in new and unregulated areas. Major pollution control laws, like the Clean Air Act and Clean Water Act, don't generally cover activities that aim to improve environmental conditions.[199] Meanwhile, the National Environmental Policy Act (NEPA), which ordinarily serves as a check on activities that may cause environmental impacts but do not fall under the umbrella of major pollution control laws, may not be applicable because it is only indicated for major federal action. Individuals, nonprofits, and other private sector actors are not bound by NEPA unless what they are doing will require federal permits, or state permits if they are operating in a state with a state-level version of NEPA.[200] The combination of new types of activities (namely those that clean up the environment instead of polluting it) and new types of actors (private sector actors that are not subject to the same procedural regulation as the government) create large regulatory gaps for the deployment of environmental silver bullets.

2. Accountability and Transparency

Accountability and transparency concerns are core to many discussions around the deployment of emerging technologies. In the case of environmental technologies, the degree of accountability varies considerably depending on which actors are using specific technologies. Understanding this landscape provides guidance for proposals to better govern emerging environmental technologies.

Though sometimes flawed in its execution, accountability is a core goal of public agencies.[201] Accountability principles are imbued throughout environmental agency processes and mandates. For environmental technologies, this means that technology deployment is subject to extensive oversight. Any technological changes that require updates to existing federal regulations are subject to the Administrative Procedure Act's notice and comment process,

196. Vandenbergh, *supra* note 19, at 177–78.
197. *See id.*
198. *See, e.g.*, Ellison, *supra* note 192.
199. The aim of these laws instead focuses on preventing pollution.
200. *See* National Environmental Policy Act, 42 U.S.C. § 4332.
201. *See* Joshua Ulan Galperin, *Environmental Governance at the Edge of Democracy*, 39 VA. ENV'T L. J. 70, 92 (2021).

allowing public participation in technology governance.[202] These processes often slow adoption of new technologies, but, at least in theory, they also ensure that emerging technologies have been extensively reviewed before adoption by government agencies. In many cases, new technology itself is used to facilitate transparency by disseminating information about public activities.[203]

There are certainly areas in which government agencies are not as accountable as they should be. For instance, public accountability is notably less in international environmental action, as well as in public-private partnerships.[204] Agency adoption of AI technologies has garnered significant pushback in areas outside of environmental law.[205] Improved surveillance technologies, for instance those being deployed on fishing vessels, come with concerns about privacy and fears from regulated industries that they will not have a choice about which tools agencies choose to deploy and how they will use the data that is generated.[206] These concerns are not trivial, but in comparison to other types of actors, government entities are generally subject to much higher degrees of accountability in their adoption and deployment of new technological tools. [207]

Technology deployment in the private sector is not generally subject to the same degree of accountability as in government.[208] This is true for corporations, as well as for NGOs and private individuals.[209] Nonprofits tackle issues ranging from the trivial to the significant, and there is no requirement that their actions go through the same cost-benefit accounting that many federal actions must, nor that they survive democratic scrutiny. The result is that many nonprofits focus on relatively narrow issues in ways that the government cannot. Moreover, unlike corporations that ultimately seek to create products that others will buy, nonprofits have no such aims. In the case of environmental technologies, this is an important difference. Nonprofits developing technologies are not aiming to sell their technologies, and so they are not as attuned to the needs of customers. On the one hand, this creates a much more open landscape for nonprofits to

202. Administrative Procedure Act, 5 U.S.C. § 552.

203. *See generally* MCGUINNESS & SCHANK, *supra* note 6.

204. *See* VANDENBERGH & GILLIGAN, *supra* note 194, at 385.

205. *See, e.g.*, Danielle K. Citron & Ryan Calo, *The Automated Administrative State A Crisis of Legitimacy* 5 (B.U. L. Sch. Working Paper) (2020), https://scholarship.law.bu.edu/faculty_scholarship/838/.

206. Garren et al., *supra* note 98, at 104, 635–36; Monica Medina & Scott Nuzum, *Electronic Reporting and Monitoring in Fisheries Data Privacy, Security, and Management Challenges and 21st-Century Solutions*, 49 Env't L. Rep. (Env't Law Inst.) 10,670, 10,685–86 (2019).

207. *See, e.g.*, David E. Pozen, *Transparency's Ideological Drift*, 128 YALE L. J. 100, 102 (2018) (describing the accountability mechanisms built into public administration).

208. *See* VANDENBERGH & GILLIGAN, *supra* note 194, at 384 ("This concern is grounded in the idea that public governments are accountable to the citizens in democratic countries through a variety of mechanisms, but private initiatives sometimes play governmental roles without being subject to these same accountability mechanisms.").

209. Sarah Light & Eric Orts, *Parallels in Public and Private Environmental Governance*, 5 MICH. J. ENV'T & ADMIN. L. 1, 63 (2015).

operate in, allowing them to provide public goods that may not have market value. On the other hand, NGOs, particularly those that don't rely on individual donations, may have fewer market accountability mechanisms than corporations or government entities.

However, proponents of PEG note that private sector actors have accountability through various private ordering mechanisms, from market incentives to reputation risk.[210] Private activities that include consortiums of companies partnering with NGOs or public sector actors are likely to be more accountable because they create new mechanisms for engagement and transparency.[211]

Likewise, NGOs that are reliant on donations from individuals and foundations may incorporate accountability mechanisms as a core piece of their funding model. Receiving funding from foundations, for instance, comes with significant monitoring and evaluation requirements. Technology projects would be subject to these mandates. External organizations like Charity Navigator provide additional oversight over NGOs for members of the public or others interested in donating.[212] Federal oversight through 501(c)(3) status provides some additional measure of accountability, too.[213]

The largest problems with accountability stem from technologies that are deployed by wealthy individuals. Wealthy philanthropists tend to undertake environmental projects either out of a desire to be altruistic or because they want to improve their public image (or perhaps most frequently, some combination of the two). Public approval can serve as its own version of accountability for those who make visibility a goal of environmental giving. This is an important form of accountability, but a weak one. Wealthy individuals can choose which activities to advertise to the public and to what degree they wish to be transparent about them. Public perception of these activities tends to lack nuance or deep understanding, often celebrating wealthy individuals who undertake charitable acts without much deeper investigation.[214]

The consequences of the lack of accountability among the environmental projects spearheaded by wealthy individuals manifests itself in several ways. There is no requirement that wealthy philanthropists be truly transparent about their activities. Outcome tracking is something of an obsession for nonprofits, with an entire industry created around how success metrics should be developed

210. Galperin, *supra* note 201, at 92.

211. *See* VANDENBERGH & GILLIGAN, *supra* note 194, at 385.

212. *See generally* CHARITY NAVIGATOR, https://www.charitynavigator.org/ (last visited Dec. 22, 2022).

213. The IRS requires that 501(c)(3) nonprofits "must not be organized or operated for the benefit of private interests." *See Inurement/Private Benefit—Charitable Organizations*, IRS, https://www.irs.gov/charities-non-profits/charitable-organizations/inurement-private-benefit-charitable-organizations (last visited Dec. 15, 2022).

214. *See* CALLAHAN, *supra* note 7, at 5–6 (noting that in the late twentieth century, Americans were "uncritical" in celebrating the philanthropy of wealthy individuals).

and assessed.[215] Showing past results is necessary to continue getting funding in the future. Philanthropists, on the other hand, are accountable to no one, and, while some may choose to undertake their own versions of outcome tracking, by and large this information remains out of public view. Additionally, many philanthropic efforts centered on environmental technology innovations have chosen to incorporate not under the traditional foundation model, but as Limited Liability Companies (LLCs). This shift undermines core regulatory efforts to limit philanthropic ills and decreases potential accountability.[216]

Technology projects pioneered by individuals operate with less accountability and transparency, and, as a result, are more likely to have unanticipated negative outcomes. Sometimes these outcomes are relatively benign: scientists agree that Mark Benioff's Trillion Trees initiative is not likely to have the success it claims and view it as a very inefficient use of money[217] Individuals are not tied into the same demand networks and accountability mechanisms as nonprofits and private individuals, so this type of inefficient outcome is incredibly common. Sometimes, though, the results are more detrimental, for instance iron fertilization experiments or genetic control attempts that can lead to widespread disruption of ecosystem dynamics.[218]

3. Environmental Justice

Building on accountability concerns, silver bullet technologies raise environmental justice questions that must be considered moving forward. Environmental technologies are emerging into already complicated social systems. How they are used will reflect existing power dynamics.[219] While emerging technologies are routinely touted for their ability to democratize environmental engagement, in practice, whether these technologies work to broaden participation or merely to concentrate power in the hands of those that already have it remains to be seen.[220] Providing individuals with opportunities outside of traditional voting to engage with environmental issues may be

215. *See e.g.* John Sawhill and David Williamson, *Measuring what matters in nonprofits* (May 1, 2001), https://www.mckinsey.com/industries/public-and-social-sector/our-insights/measuring-what-matters-in-nonprofits (describing McKinsey's approach to impact tracking).

216. Eric Franklin Amarante, *The Perils of Philanthrocapitalism*, 78 U. MD. L. REV. 1, 4 (2016).

217. *See* Patrick Greenfield, *I've Never Said We Should Plant a Trillion Trees' What Ecopreneur Thomas Crowther Did Next*, GUARDIAN (Sept. 1, 2021), https://www.theguardian.com/environment/2021/sep/01/ive-never-said-we-should-plant-a-trillion-trees-what-ecopreneur-thomas-crowther-did-next-aoe (describing the "intense scientific criticism" of the Trillion Trees Initiative).

218. *See, e.g.*, Raphael Sagarin et al., *Iron Fertilization in the Ocean for Climate Mitigation Legal, Economic, and Environmental Challenges* 5 (Duke Univ. Nicholas Inst. Env't Pol'y Sols. Working Paper No. NI WP 07-07) (2007); Jonathan B. Wiener & Michael D. Rogers, *Comparing Precaution in the United States and Europe*, 5 J. RISK RSCH. 317, 318, 323(2011).

219. Jack Balkin, *The Path of Robotics Law*, 6 CALIF. L. REV. CIR. 45, 47 (2015) ("Technology, like law, mediates social relations between human beings—including relations of power and control.").

220. *See, e.g.*, SHEILA JASANOFF, THE ETHICS OF INVENTION 5 (2016) ("The benefits of technology remain unevenly distributed, and invention may even widen some of the gaps.").

necessary for an optimal democratic system, but it is short-sighted to rely on technology alone to provide these avenues.[221]

In other sectors, technology has become another way to cement power among those who already have it. Technology is often deployed to reflect and reinforce existing power disparities between different groups.[222] There is no indication that the adoption of environmental technologies will break from this precedent. In the environmental landscape, the history of environmental technology has largely led to more efficient, and therefore more devastating, exploitation of natural resources.[223] Excitement about the potential for technologies to help solve environmental issues is inevitably followed by the adoption of these technologies by private sector actors looking to improve economic outcomes, and not by public sector decision-makers or community groups looking to protect environmental conditions.

Environmental justice issues are particularly apparent when it comes to technologies that are pioneered by wealthy individuals. These private actors tend to carry out projects that are personally motivated and may have little relevance to societal needs, even when billionaires believe they do.[224] The resulting patchwork of investment in global problems is not reflective of any sort of optimal outcome, but instead the whims of a handful of very wealthy individuals. The priorities of these individuals, and the technologies that result, are disconnected from the needs of the majority of the global population.[225] Many have argued that this type of environmental action is inherently undemocratic because it prioritizes the opinions of certain individuals over others based on wealth and social class.[226] Technology exacerbates this undemocratic nature, raising the stakes of what individuals can achieve, as well as the consequences of their actions.

III. TECHNOLOGY CASE STUDIES

Technology is enabling private sector actors to move beyond traditional mechanisms for engaging in environmental governance. Private actors that wish to actively conserve and remediate ecosystem damage are leveraging new technological developments, creating opportunities for transformative impact on previously impossible scales. Characterized by high speeds of project

221. Galperin, *supra* note 201, at 86 ("A democratic system, therefore, must also include an authentically individual component, creating structures through which individuals can seek change regardless of whether they are counted as part of an electoral majority.").

222. *See generally* Ziaja, *supra* note 120 (analyzing how algorithmic decision-making can be in tension with transparency, accountability, equity, and broad stakeholder participation).

223. *See* Ochoa, *supra* note 59, at 150–51; Grant, *supra* note 60; Owen, *supra* note 88, at 250–51.

224. Amarante, *supra* note 216, at 5–6.

225. Compare, for instance, the billions of dollars being spent on efforts to remove plastics from the ocean with the much smaller investments in clean water infrastructure, a critical environmental and public health threat for much of the globe.

226. Amarante, *supra* note 216, at 5.

deployment and low levels of accountability, these projects present new challenges for environmental regulation. Turning to technological solutions as a panacea to save us from environmental problems is not a new phenomenon.[227] What is new is the volume of resources individual actors are putting into technological solutions.

This Part explores two case studies to show in detail how private sector actors are using technology to take on new types of environmental action. I describe how these technologies are potentially revolutionary in their impacts on the environment at the same time as they operate in gaps in traditional regulatory frameworks. These case studies raise important questions not only about governance, but also about how to ensure equity and accountability for environmental solutions that are increasingly driven by individual wealthy actors.[228]

A. Ocean Plastics

Only recently have scientists begun to debunk the notion that the ocean is too big to fail.[229] In 2019, an expedition to the bottom of the Mariana Trench, nearly six miles beneath the ocean's surface, discovered microplastics in the water.[230] 75 percent of the world's coral reefs are severely threatened.[231] No part of the ocean remains free of human impact.

The extent of these impacts has galvanized global awareness and catalyzed a new wave of ocean technologies that seek to mitigate environmental damage and restore ocean conditions. Nowhere has enthusiasm been greater than around proposed solutions to ocean plastic pollution. Scientists estimate that up to twelve million tons of plastic currently enter the ocean each year, a number that could increase by tenfold in the coming decade.[232] Concerns about the impacts of plastic on marine ecosystems have led to a global movement focused on eliminating marine plastic pollution.[233] However, solving the plastics problem is far from simple. Plastics enter the ocean from a variety of land-based sources and, once in the ocean, quickly disperse and break down into microplastic

227. MCGUINNESS & SCHANK, *supra* note 6, at 71 ("The lure of starting with technology, or technology as panacea, can be hard to overcome.").

228. *See* REICH, *supra* note 179, at 148–52, 182.

229. Jane Lubchenco & Steven D. Gaines, *A New Narrative for the Ocean*, 364 SCIENCE 911, 911 (2019).

230. Jack Wilkin, *Plastic at the Bottom of Mariana Trench*, ECOLOGIST (May 31, 2019), https://theecologist.org/2019/may/31/plastic-bottom-mariana-trench.

231. LAURETTA BURKE ET AL., REEFS AT RISK REVISITED 3 (2011).

232. Jenna R. Jambeck et al., *Plastic Waste Inputs From Land Into the Ocean*, 347 SCIENCE 768, 768–70 (2015).

233. *See, e.g.*, S. B. Sheavly & K. M. Register, *Marine Debris & Plastics Environmental Concerns, Sources, Impacts and Solutions*, 15 J. POLYMERS & ENV'T 301 (2007); Sasha G. Tetu et al., *Plastic Leachates Impair Growth and Oxygen Production in* Prochlorococcus, *the Ocean's Most Abundant Photosynthetic Bacteria*, 2 COMMC'NS BIOLOGY 184 (2019).

particles.[234] The many sources combined with global reliance on plastics in many products make this a nearly insurmountable problem.

Several technology companies have stepped into the fray to try to remove plastics from the ocean and restore ocean ecosystems.[235] The Ocean Cleanup is one of these technologies.[236] Since 18-year old Boyan Slat made a viral video on ocean plastics in 2018, The Ocean Cleanup's system of using booms and nets to clean plastics from the ocean has been a popular approach to solving the ocean plastics problem.[237] The Ocean Cleanup has raised over fifty million dollars, including sponsorship from some of the most prominent maritime companies in the world and crowd-funded contributions from millions.[238]

The rise of The Ocean Cleanup illustrates how quickly silver bullets can move from barebones ideas to well-funded technologies with large-scale deployment plans. In the case of The Ocean Cleanup, Boyan Slat was able to rapidly gain notoriety through viral social media posts.[239] This quickly led to his project being championed by Mark Benioff, who has a long-standing commitment to funding conservation projects and is particularly interested in startups that provide technological solutions to environmental problems.[240] Mark Benioff also happens to be a major funder of the World Economic Forum's efforts to improve ocean sustainability outcomes, and his chosen projects have the opportunity to reach the movers and shakers of the world.[241] Benioff championed The Ocean Cleanup to these groups, and Boyan Slat quickly was accepted and embraced by the Davos crowd, leading to significant governmental and financial support.[242]

234. Sarah Gibbens, *Plastic Proliferates at the Bottom of the Mariana Trench*, NAT'L GEOGRAPHIC (May 13, 2019), https://www.nationalgeographic.com/science/article/plastic-bag-mariana-trench-pollution-science-spd.

235. Emma Schmaltz et al., *Plastic Pollution Solutions Emerging Technologies to Prevent and Collect Marine Plastic Pollution*, 144 ENV'T INT'L. 106,067, 106,072–75 (2020).

236. *See* THE OCEAN CLEANUP, *supra* note 12.

237. *About Us*, OCEAN CLEANUP, https://theoceancleanup.com/about/ (last visited Dec. 15, 2022).

238. Dickie, *supra* note 2; Ron Kaplan, *The Ocean Cleanup Project And The Ocean Plastic Crisis What Investors Can Learn From Failing Fast*, FORBES (Mar. 19, 2019), https://www.forbes.com/sites/robkaplan/2019/03/19/the-great-garbage-patch-and-the-ocean-plastic-crisis-what-investors-can-learn-from-failing-fast/?sh=49cca9071b9a ("The Project quickly became a media phenomenon and—somewhat more surprisingly given its nonprofit status, a Silicon Valley darling.").

239. *How It All Began*, OCEAN CLEANUP, https://theoceancleanup.com/milestones/how-it-all-began/ (last visited Dec. 22, 2022) (describing how Slat's TEDx talk went viral and in a matter of days enabled The Ocean Cleanup to hire their initial team).

240. In the words of Benioff "ecopreneurs." Sammy Spiegel, *A New Environmental Capitalism' Is Needed Benioff and Other Salesforce Execs Speak at Davos*, SALESFORCE (May 25, 2022), https://www.salesforce.com/news/stories/salesforce-davos-2022/.

241. FRIENDS OF OCEAN ACTION, *supra* note 181 (noting Marc Benioff's foundational funding role in the Friends of Ocean Action, a high-level group of CEOs, former heads of state and other ocean champions convened by the World Economic Forum).

242. The Ocean Cleanup is part of a network of World Economic Forum-convened partnerships, including the Global Plastic Action Partnership. Press Release, Glob. Plastic Action P'ship, World

While The Ocean Cleanup is the darling of billionaires and Fortune 500s, it is also the bane of marine scientists.[243] Some initial attempts by scientists to collaborate with The Ocean Cleanup to address concerns about environmental impacts were ignored.[244] Instead, The Ocean Cleanup launched a smear campaign to discredit prominent marine scientists who had raised questions about its plans.[245] Proving these concerns reasonable, less than four months after the initial prototype was launched, The Ocean Cleanup announced that its device had broken irreparably and was being towed back to shore.[246] As predicted by scientists, the design of the device was not able to withstand ocean winds and waves.[247] In the years since 2018, The Ocean Cleanup has unsuccessfully launched other prototype missions, wasting tons of fuel and money, while gathering minimal amounts of ocean plastics.[248]

The Ocean Cleanup has exposed the systemic differences between the technology and scientific communities. Where scientists are focused on iterative long-term rigor, the startup community is notorious for its "move fast and break things" ethos.[249] When it comes to environmental technologies, The Ocean Cleanup suggests that private ordering is unlikely to ensure that conservation technologies are scientifically sound. Despite public outcry from scientists, some of whom sent The Ocean Cleanup detailed environmental impact assessments, The Ocean Cleanup refused to respond to this discourse and continued its operations without scientific collaboration.[250] Other disruptive technology projects looking to achieve rapid environmental results are likely to follow this same model, relying on their own funding successes and momentum to push projects forward and ignore scientific scrutiny that may bog the project down.

The Ocean Cleanup case study also highlights how gaps in regulation allow large-scale private enterprises to move forward with relatively little scientific or legal oversight. This is untenable, especially considering the increase in solutions seeking to mitigate environmental damage at a global scale.

In the case of The Ocean Cleanup, the project's technology did not fall into existing regulatory categories under the United Nations Convention on the Law of the Sea (UNCLOS), allowing it to operate with relatively little legal

Economic Forum's Plastic Pollution Platform Announces New Civil Society, Business Partners at Davos Agenda (Jan. 25, 2021), https://globalplasticaction.org/pressrelease/gpap-new-members-davos-agenda/.

243. *See, e.g.*, *Goldstein & Martini*, *supra* note 3.

244. *Id.*

245. Dickie, *supra* note 2.

246. *System 001—First Ocean Cleanup System*, OCEAN CLEANUP, https://theoceancleanup.com/milestones/system001/ (last visited Dec. 22, 2022).

247. *Id.*

248. Dickie, *supra* note 2 (noting that "prone to seasickness, The Ocean Cleanup's young Dutch founder Boyan Slat does not often venture out onto the open ocean and can't fully see why his project is failing but, after 120 hours of deployment last month, his vessels burned tons of fuel to scoop up less than a single garbage truck's standard haul.").

249. Hemant Taneja, *The Era of "Move Fast and Break Things" is Over*, HARV. BUS. REV. (Jan. 22, 2019), https://hbr.org/2019/01/the-era-of-move-fast-and-break-things-is-over.

250. *See* Goldstein & Martini, *supra* note 3.

oversight.[251] In order to avoid concerns that its activities were operating completely outside of international maritime law, The Ocean Cleanup partnered with the Dutch government in an agreement that allowed The Ocean Cleanup to carry out "Marine Scientific Research" under the auspices of the Netherlands.[252] Marine Scientific Research (MSR) is protected as a freedom under UNCLOS, and it can only be undertaken by states.[253] The argument that The Ocean Cleanup was engaging in MSR is weak at best: the clear mission of the project was to remove plastics from the ocean, not to contribute to scientific knowledge.[254] Despite this, friends in high places and widespread public endorsement allowed The Ocean Cleanup to garner the government support needed to allow the project to continue.[255]

Whether or not The Ocean Cleanup was engaging in MSR, it was still bound by the UNCLOS provisions on protecting the marine environment. The UNCLOS provisions mandating marine biodiversity protection apply in all areas of the ocean, and they direct that "states have the obligation to protect and preserve the marine environment."[256] States have an active duty under Article 194 to "take, individually or jointly as appropriate, all measures consistent with this Convention that are necessary to prevent, reduce and control pollution of the marine environment from any source."[257] Article 194 serves as the primary legal justification for efforts to remove plastics from the marine environment.[258] UNCLOS does limit the duty in Article 195: "In taking measures to prevent, reduce and control pollution of the marine environment, States shall act so as not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into another."[259] This is an important safeguard on efforts to remediate ocean pollution, theoretically preventing potentially harmful technology interventions. However, the Law of the Sea lacks the teeth to effectively enforce these provisions, allowing technologies like The Ocean Cleanup to move forward.

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251. Notably, UNCLOS primarily governs the activities of "vessels." Whether emerging types of maritime technologies are vessels remains unclear. *See* Claude Jost & Kevin Karlen, *The Agreement Between the Netherlands and The Ocean Cleanup*, LEIDEN L. BLOG (Aug. 16, 2018), https://leidenlawblog.nl/articles/the-agreement-between-the-netherlands-and-the-ocean-cleanup ("On account of the system's uniqueness, the Parties found that it is not immediately apparent what the applicable regulations are, and concluded that no ready-made legal framework exists.").

252. *Id.*

253. United Nations Convention on the Law of the Sea arts. 238–239, Dec. 10, 1982, 1833 U.N.T.S. 397, 495 [*hereinafter* UNCLOS].

254. Even the academics tasked with making the case that The Ocean Cleanup qualifies as research stated merely that The Ocean Cleanup "might fulfil these criteria and, if deemed beneficial for its activities, it could hence strive to conduct MSR under a state's flag." Jost & Karlen, *supra* note 251.

255. The Ocean Cleanup's core supporters include Maersk, Coca-Cola, Deloitte, and the Netherlands Government. *See Partners*, OCEAN CLEANUP, https://theoceancleanup.com/partners/ (last visited Dec. 22, 2022).

256. UNCLOS, *supra* note 253, art. 192.

257. *Id.* art. 194(1).

258. Jost & Karlen, *supra* note 251.

259. *Id.* art. 195.

Other new technologies are confounding classification under Law of the Sea. The freedom of navigation allows every state the "right to sail ships flying its flag on the high seas."[260] UNCLOS provides little clarity on what the "right to sail" encompasses or what vessels can be considered ships. The latter question has been the subject of a great deal of debate and interest in recent years as autonomous vessels, scientific gliders, and other emerging ocean-going craft stretch the UNCLOS conception of what a ship is.[261] When UNCLOS was passed in the 1980s, there was little debate on this point because no one envisioned a future with the myriad unmanned craft that we have today.[262] Emerging technological interventions, many of which are autonomous or unmanned, fall into a definitional gray area, opening up opportunities to operate relatively free of legal oversight.

Even in cases where emerging technologies are recognized as vessels under the Law of the Sea, enforcement on the high seas is notoriously difficult.[263] Interventions like The Ocean Cleanup, with good if misguided intentions, are unlikely to be a priority for the limited enforcement resources that do exist. This is particularly true in cases where significant public support may cause regulatory agencies to overlook potential long-term consequences. Determining whether technologies are negatively impacting the environment after they have been deployed is something that most maritime regulators are ill-equipped to handle, particularly in areas outside of their coastal waters. Governance mechanisms that can put effective constraints on technological interventions before they are deployed are essential.

The lack of legal oversight and enforcement resources is particularly stark in Areas Beyond National Jurisdiction, or the high seas. The high seas cover 64 percent of the world's oceans and lack the legal and practical oversight that governs coastal waters.[264] While more distant and difficult to reach, these areas are often prime candidates for technology interventions. Scientifically, the open ocean contains many of the areas that are best suited for intervention: for instance, gyres that concentrate plastics or nutrient limited areas ripe for fertilization.[265] Legally, these areas are only governed by UNCLOS, so no approval is needed from coastal states that may be unwilling to take risks in their

260. *Id.* art. 90.

261. *See, e.g.*, Craig H. Allen, *The Seabots are ~~Coming~~ Here Should They be Treated as Vessels' ?*, 65 J. NAVIGATION 749, 750 (2012); Craig H. Allen, *Determining the Legal Status of Unmanned Maritime Vehicles Formalism vs Functionalism*, 49 J. MAR. L. COM. 477, 488–96 (2018); Stephanie Showalter, *The Legal Status of Autonomous Underwater Vehicles*, 38 MARINE TECH. SOC'Y J. 80, 80 (2004); Henrik Ringbom, *Regulating Autonomous Ships—Concepts, Challenges and Precedents*, 50 OCEAN DEV. & INT'L L. 1, 21 (2019); Daniel A.G. Vallejo, *Electric Currents Programming Legal Status Into Autonomous Unmanned Maritime Vehicles*, 47 CASE W. RSRV. J. INT'L L. 405, 407–08 (2015).

262. *See* Allen, *supra* note 261, at 480–88.

263. *See, e.g.*, Douglas Guilfoyle, *Maritime Law Enforcement Operations and Intelligence in an Age of Maritime Security*, 93 INT'L L. STUDS. 298, 304 (2017).

264. *Future of the High Seas Hangs in the Balance*, ECONOMIST IMPACT (Sept. 16, 2022), https://ocean.economist.com/governance/articles/future-of-the-high-seas-hangs-in-the-balance.

265. *See* Sagarin et al., *supra* note 218, at 3–5 (discussing iron fertilization).

own Exclusive Economic Zones.[266] Technology projects that can operate without running flagrantly afoul of UNCLOS's marine biodiversity protections have few other constraints in these areas.[267]

B. De-Extinction and Genetic Modification

Biodiversity loss poses an existential threat to the environment, and this problem resists policy solutions as it escalates in magnitude globally.[268] As with other wicked environmental problems, new technological tools are providing opportunities for solutions. In the case of biodiversity loss, many of these solutions focus on using genetic techniques to preserve species, increase adaptability, and even eliminate undesirable species entirely from ecosystems.[269]

The public sector is cautiously beginning to adopt some of these techniques,[270] but the real action in genetic environmental research is in the private sector. De-extinction efforts are some of the most controversial of these efforts, but, unsurprisingly, are the darlings of many wealthy private individuals.

Revive and Restore, one organization leading this charge, aims to use new genetic technologies to both protect currently threatened species as well as bring back those that are long extinct.[271] One early project aims to resurrect the passenger pigeon as a model for future de-extinction efforts. While ultimate release of passenger pigeons into the wild may be a decade away, early genetic work on this project is well underway to sequence and clone new passenger pigeons.[272]

These de-extinction efforts purport to protect biodiversity, preserving species that would otherwise be extinct and conferring broader environmental benefits. [273] For example, *Revive and Restore* argues that its project to de-extinct

266. UNCLOS, *supra* note 251, art. 87.

267. Note that customary international law may provide some additional guidance through the "no harm" rule, but these are generally weak mechanisms for governance. *See* ROMANY M. WEBB ET AL., COLUM. L. SCH. SABIN CTR. FOR CLIMATE CHANGE L., REMOVING CARBON DIOXIDE THROUGH OCEAN ALKALINITY ENHANCEMENT: LEGAL CHALLENGES AND OPPORTUNITIES 23–24 (2021).

268. Alejandro E. Camacho, *De- and Re-Constructing Public Governance for Biodiversity Conservation Symposium Governing Wicked Problems*, 73 VAND. L. REV. 1585, 1591–94 (2020) (arguing further that rapid declines in biodiversity coupled with behavioral and institutional barriers to developing solutions may establish biodiversity loss as a "super wicked" problem).

269. *See generally,* Alex Erwin, *Building Better Species Assisted Evolution, Genetic Engineering, and the Endangered Species Act*, 108 CORNELL L. REV. __ (forthcoming 2023).

270. *See* Waltz, *supra* note 120, at 175 (describing a pilot project releasing genetically modified mosquitoes to prevent the spread of dengue and other mosquito-borne diseases in the Florida Keys).

271. *See generally* REVIVE & RESTORE, https://reviverestore.org/ (last visited Dec. 22, 2022).

272. *Passenger Pigeon Project*, REVIVE & RESTORE, https://reviverestore.org/about-the-passenger-pigeon/ (last visited Dec. 22, 2022).

273. For example, in discussing their project to de-extinct the Passenger Pigeon, Revive & Restore notes "the Passenger Pigeon isn't simply a model species; it quite possibly is the most important species for the future of conserving the woodland biodiversity of the eastern United States. As a result, the project is now not only a model for pioneering de-extinction methods, but it offers a new opportunity to achieve long-term conservation goals for woodland forests in the eastern U.S." *Id.*

the wooly mammoth will help to mitigate impacts from global climate change.[274] For these reasons, de-extinction efforts have become darlings in Silicon Valley and among technology-oriented, wealthy individuals. *Revive & Restore*, for instance, is affiliated with and primarily funded by the Long Now Foundation, a San Francisco-based bastion of technology wealth.[275]

Many believe that the combination of private funding and technological advancements mean that de-extinction is "likely to become commonplace-sooner rather than later."[276] Despite the potential benefits, de-extinction is risky.[277] The history of human attempts to alter species distribution or introduce animals to new areas indicates that these projects almost universally have unintended consequences.[278] Ecological relationships are complex, and altering them can have cascading repercussions. The risks of genetic interventions are thus high.[279] Determining the outcomes of species reintroduction with any degree of accuracy remains nearly impossible.[280] Moreover, these environmental and scientific concerns are coupled with additional ethical questions about the role of humans in "playing god" with species and ecosystems.[281]

Despite the risks, de-extinction efforts are, for the most part, unregulated by existing environmental laws.[282] Like other technological efforts that fall into new areas of environmental action, the broad-sweeping foundational regulations of U.S. environmental policy simply do not apply.[283] Regulations limiting genetic engineering use are fragmented and, in their current forms, unlikely to apply comprehensively to environmental genetic engineering technologies.[284] While

274. *Woolly Mammoth Revival*, REVIVE & RESTORE, https://reviverestore.org/projects/woolly-mammoth/ (last visited Dec. 22, 2022) (the project "seeks to bring back the mammoth steppe ecosystem to slow the melting of the Arctic permafrost and prevent a catastrophic global warming feedback loop.").

275. *See What We Do*, REVIVE & RESTORE, https://reviverestore.org/what-we-do/ (last visited Dec. 22, 2022).

276. C. Josh Donlan, *De-Extinction in a Crisis Discipline*, 6 FRONTIERS BIOGEOGRAPHY 25, 25–26 (2014).

277. Babcock, *supra* note 13, at 172 ("Unlike genetic engineering, which offers both potential benefits and risks to humans and the environment, de-extinction appears to offer mainly risks, slightly offset by economic benefits for a few.").

278. *See* Alejandro E. Camacho, *Going the Way of the Dodo De-Extinction, Dualisms, and Reframing Conservation*, 92 WASH. U. L. REV. 849, 860 (2015) ("The history of natural resources management is rife with notorious examples of non-native introductions—some even intended to minimize other human effects on ecological resources—that nonetheless led to extensive unintended ecological harm to receiving areas."); *but see* Ben J. Novak et al., *U.S. Conservation Translocations Over a Century of Intended Consequences*, 3 CONSERVATION SCI. & PRACT. 1, 1 (2021) (finding that "only 1.4% of 3,014 biological control agents released globally have caused ecosystem-level deleterious impacts.").

279. Babcock, *supra* note 13, at 179–82.

280. Camacho, *supra* note 268, at 860.

281. *See* Babcock, *supra* note 13, at 183–84.

282. *Id.* at 184–95; Erin Okuno, *Franknstein's Mammoth Anticipating the Global Legal Framework for De-Extinction*, 43 ECOLOGY L. Q. 581, 581 (2016).

283. Babcock, *supra* note 13 at 184–85.

284. *See id.* at 171 ("The overlapping and conflicting policies governing genetic engineering, upon which de-extinction depends, have created a dysfunctional regulatory commons in which no single agency is responsible for creating, implementing, and enforcing applicable rules. Changes to this situation, even

some have proposed new governance mechanisms for de-extinction, it is unlikely that any of these will be implemented in the near future.[285] Major scientific articles, meanwhile, continue to seriously evaluate and plan for a future using these genetic tools, without even mentioning legal or regulatory concerns.[286]

De-extinction efforts are just one variety of genetic intervention in the environment. Gene drives are another increasingly popular form of genetic conservation intervention and have already been deployed in various locations around the world to attempt to limit the spread of infectious diseases.[287] In a gene drive, CRISPR alterations can speed the uptake of "favorable" genes in a wild animal population to achieve conservation goals.[288] Several countries have used this technique in mosquitoes to limit the spread of malaria and other mosquito-borne diseases, but they have been cautious in implementing these programs due to potential consequences if altered genes spread unintentionally in the ecosystem.[289] Private sector actors, on the other hand, are increasingly looking to this technology to achieve various environmental goals. The NGO Island Conservation, for example, is spearheading efforts to use gene drives as a biological control mechanism for invasive species.[290]

Despite strident calls that governance gaps must be closed and that appropriate management regimes must be implemented before gene drives or de-extinct species are released into the wild, these projects are proceeding without any comprehensive management or regulation.[291] Without meaningful formal or informal governance structures, there will be little accountability for genetic rescue projects. While new public or private environmental governance mechanisms may provide a way forward for regulating de-extinction and other environmental genetic interventions, it is uncertain when these frameworks will be implemented.[292]

These case studies highlight three key features of private sector 4IR technology deployment. First, private sector actors are using 4IR technologies to broaden the scope of environmental action, threatening more significant impacts

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if politically possible, will be too slow to respond to the intentional or unintentional release of resurrected species into the environment.").

285. Okuno, *supra* note 282, at 634; Camacho, *supra* note 268; *see also* Babcock, *supra* note 13, at 188–93.

286. *See* Michael A. Thomas et al., *Gene Tweaking for Conservation*, 501 NATURE 485, 486 (2013).

287. *See, e.g.*, Waltz, *supra* note 120; Danilo O. Carvalho et al., *Suppression of a Field Population of* Aedes aegypti *in Brazil by Sustained Release of Transgenic Male Mosquitoes*, 9 PLOS NEGLECTED TROPICAL DISEASES 1 (2015) (describing a mosquito gene drive example in Brazil).

288. CRISPR genome editing allows scientists to relatively easily introduce desired genetic modifications into target species, for instance to avoid genetic variations that will make individuals infertile. Kevin M. Esvelt & Neil J. Gemmell, *Conservation Demands Safe Gene Drive*, 15 PLOS BIOLOGY 1, 1–2 (2017).

289. Waltz, *supra* note 120, at 176.

290. *Genetic Biocontrol of Invasive Rodents*, ISLAND CONSERVATION, https://www.geneticbiocontrol.org/ (last visited Dec. 22, 2022).

291. Babcock, *supra* note 13, at 195.

292. *See id*. at 184–95.

than we have seen before. CRISPR technologies put gene editing technology in the hands of the public, opening the potential for catastrophic and cascading impacts. Large physical technologies like The Ocean Cleanup championed by private individuals have the potential to cause ecosystem-wide damage even though they were marketed as providing environmental benefits. The scale of potential impacts created by new private sector technologies raises serious questions about how these technologies will be managed moving forward. The fact that these technologies are being implemented by private actors, not public sector actors, represents a shift in how environmental remediation is carried out.

This brings up to the second important takeaway from the current deployment of environmental silver bullets: in most cases these technologies are operating outside of existing regulatory frameworks. In both the case of oceanic plastic pollution and that of genetic interventions, emerging technologies are enabling new types of engagement with the environment that are not governed by existing regulation. The novelty of these technologies makes determining their impacts on complex ecosystems particularly difficult, and it is impossible to know whether environmental silver bullets will have net positive or negative impacts on the environment. Governance measures are needed to adequately understand and mitigate the consequences of environmental technologies.

Lastly, large-scale technologies deployed by private sector actors are resulting in widespread decreases in accountability. While public sector technology adoption is not without its flaws when it comes to transparency, the existence of government procurement and procedural requirements ensures that some level of accountability is available. This is not the case when it comes to private sector actors. Both The Ocean Cleanup and major de-extinction efforts are being carried out by private sector actors with very low levels of transparency or accountability. This is problematic not only for the potential negative impacts of these technologies, but also for their role in reinforcing existing inequities in how environmental problems are identified, prioritized, and ultimately addressed.

IV. IMPROVING ACCOUNTABILITY FOR ENVIRONMENTAL TECHNOLOGIES

Efforts to clean up ocean plastics and prevent species extinction illustrate new ways in which private sector actors are trying to use technology to mitigate challenging environmental problems. These two projects are exemplars of environmental silver bullets: solutions that can be rapidly deployed, at scale, with relatively little governmental oversight. There are myriad other technologies in this category, such as climate geoengineering solutions and 3D printed rhinoceros' horns.[293]

293. *See* MCGUINNESS & SHANK, *supra* note 6, at 57 (describing the prevalence of silver bullet technologies); Benji Jones, *Fake Rhino Horns Were Supposed to Foil Poachers. What Went Wrong?* VOX (Oct. 18, 2021), https://www.vox.com/down-to-earth/22723289/3d-printed-rhino-horn-wildlife-conservation-poaching; Patrick W. Keys et al., *Could Solar Geoengineering be the Answer to Slowing*

This Part draws on the lessons of these case studies to argue that lack of accountability is the core concern with emerging environmental silver bullets. Creating both formal and informal mechanisms to improve accountability is critical in determining whether the impact of 4IR technologies on the environment is ultimately a success story or a cautionary tale. The examples of ocean plastics and genetic rescue technologies show how private sector actors are rapidly deploying new technologies at scale without meaningful formal governance or other accountability mechanisms. While much current discussion focuses on how formal regulatory mechanisms are failing to provide effective oversight for emerging technologies,[294] I argue here that private sector and informal accountability mechanisms may prove more important in governing large-scale environmental technology projects. Evaluating technology interventions on their degree of accountability can inform where regulatory action is most urgently needed to ensure positive environmental outcomes.

A. Formal Accountability Through Regulation

Tradeoffs are inherent in environmental management.[295] Nearly every environmental project comes with consequences, from wind turbines that kill birds, to electric car batteries that require rare earth minerals from the deep sea.[296] One of the major roles of government agencies in environmental management is to weigh these tradeoffs and develop mechanisms for helping to carry out cost-benefit analyses to ensure long-term sustainability. In the United States, the government does this through both substantive and procedural rules. First, the government sets minimum requirements for environmental "floors": for example, acceptable levels of pollution, beyond which we are unwilling to accept more, regardless of the economic benefits of the activities that generated them. In the case of emerging environmental technologies, these existing substantive laws and regulations provide limited guidance. Many of the problems that new technologies are being deployed to fix are not like the classic cases of water or air pollution that major environmental laws target.

Creating new laws to address all the different ways that environmental technologies are being deployed is likely infeasible, not just politically, but also practically, given the difficulty of passing new environmental law. Realistically, determining the substantive impacts across the diffuse landscape of technologies is likely impossible. Even in relatively circumscribed subfields of the environment, passing laws to govern new technologies has been extremely

Global Warming?, WORLD ECON. F. (Sept. 29, 2022), https://www.weforum.org/agenda/2022/09/solar-geoengineering-temperature-global-warming-climate-change/.

294. *See, e.g.*, Ziaja, *supra* note 120, at 913–14; *see* Okuno, *supra* note 282, at 593; Camacho, *supra* note 268, at 855.

295. *See, e.g.*, Tomasovic, *supra* note 11, at 105–119 (discussing the role of tradeoffs in environmental law).

296. *See id*. at 94 (discussing wind turbine impacts on birds); Ardron et al., *supra* note 178 (discussing negative consequences of mining deep sea ecosystems to supply battery components).

difficult. For instance, in fisheries, keeping management regulations updated as technology evolves has been so difficult that even in 2022 management regimes require hard drives with raw data to be mailed to government offices.[297] These difficulties are compounded by the rapidly evolving nature of technology: if a law were to be passed, it would almost immediately be outdated.[298]

In lieu of major substantive legislation to mitigate adverse environmental impacts, the government also addresses environmental harms through procedural law and regulation. The National Environmental Policy Act (NEPA) is the cornerstone of these procedural requirements, mandating that major projects go through extensive environmental impact analysis before they are approved.[299] This type of legislation is a more suitable mechanism for regulating the potential adverse impacts of environmental technologies: requiring technology projects to fully evaluate negative consequences before they are deployed, as NEPA does, would provide much-needed accountability for emerging technologies by requiring and publicizing environmental impact analysis. In some cases, of course, technology projects will be required to go through NEPA already. But the unpermitted, private sector nature of many of these projects increasingly exempts large-scale environmental projects from having to complete environmental impact analysis.

Procedural laws, like NEPA, that encourage a more thorough weighing of the cost-benefit tradeoffs for emerging technologies would do a great deal to improve accountability and decrease the negative environmental outcomes of these technologies. However, subjecting emerging technologies to NEPA-like processes is likely not an optimal course of action due to the procedural delays and bureaucratic hurdles that complying with NEPA would entail. Despite their potential consequences, emerging technologies present important opportunities to improve environmental outcomes. Governance of these technologies must strike a balance that incentivizes and does not slow down innovation at the same time as it protects society from negative outcomes. NEPA is notorious and controversial for its resource- and time-intensive process and is likely not the best way to strike this balance.[300] Studies have shown, for instance, that it took more than four and a half years on average between when an initial notice of intent to prepare an Environmental Impact Statement under NEPA was issued and when the final EIS was completed.[301] For large, established companies, this already represents a difficult barrier to project deployment. For the relatively

297. WESTFALL ET AL., *supra* note 117, at 5.

298. *See, e.g.*, Balkin, *supra* note 219, at 59–60 ("What seems particularly important and salient about technology changes over time as people work with and through new technology . . . our assessment of what is most interesting or worrisome about a technology may change.").

299. *See* National Environmental Policy Act, 42 U.S.C. § 4332(c); Bradley C. Karkkainen, *Toward a Smarter NEPA Monitoring and Managing Government's Environmental Performance*, 102 COLUM. L. REV. 903, 905 (2002).

300. *See* Karkkainen, *supra* note 299, at 905.

301. Michael Gerrard, *Legal Pathways for a Massive Increase in Utility-Scale Renewable Generation Capacity*, 47 Env't L. Rep. (Env't Law Inst.) 10,591, 10,603 (2017).

small startups that are often leading development of new environmental technologies, this is likely to be an insurmountable barrier to success. Some have gone so far as to argue that significant modifications to NEPA are needed to ensure that it does not pose an undue obstacle to development of renewable energy infrastructure and other methods to mitigate climate change.[302]

B. Informal Accountability Mechanisms

Formal governance measures have widely struggled to adapt effectively to emerging technologies, both in the environmental arena and outside of it. The most promising mechanisms for governing emerging technologies will likely turn on a mix of formal and informal structures. Informal mechanisms that work to improve accountability and transparency for emerging technologies will be essential to determining potential impacts on the environment and assessing whether additional governance measures need to be implemented.

Soft law, or private governance strategies, have become an important feature of environmental governance in the past few decades, providing a mechanism to drive environmental outcomes in areas where formal regulation has failed. These strategies rely on private sector collaboration among companies or non-governmental organizations to create voluntary standards or other tools to promote environmental compliance. Soft law approaches are likely to be essential to governing emerging technologies.[303]

The advent of rapidly evolving and potentially paradigm-shifting technologies in other areas has pushed private sector actors to create informal accountability systems in lieu of federal regulation. Social media companies have been the most visible examples of this, evolving their own sophisticated private governance mechanisms in the absence of governmental oversight.[304] Likewise, the role of NGOs in providing accountability for other environmental actors is significant, with many nonprofit efforts designed specifically to increase information transparency and overall accountability for both public and private sector actors. These efforts range from public-information campaigns, to certification programs, to direct litigation.[305]

Environmental technologies pose many of the same problems as emerging technologies more broadly and will likely require that private actors develop new governance mechanisms. In many cases, companies creating new technological solutions to environmental problems do so in areas where there is little regulatory oversight. Accountability is not inherent for private actors, but public pressure,

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302. *Id.*

303. Hagemann et al., *supra* note 25, at 40–42.

304. *See generally* Kate Klonick, *The New Governors the People, Rules, and Processes Governing Online Speech*, 131 HARV. L. REV. 1598 (2018).

305. *See, e.g.,* MALONE & PASTERNACK, *supra* note 153, at 292–93 (discussing the different strategies available to NGOs to enforce environmental law).

combined with market-based incentives, can work to ensure accountability in the face of rapid technology adoption.

Going forward, strategies to regulate environmental technologies should focus both on improving formal governance through better regulation, as well as on strengthening informal accountability mechanisms. Several scholars have already pointed to soft law strategies for their potential to help regulate emerging technologies.[306] These approaches can provide solutions that improve accountability without unnecessarily stifling innovation in emerging technologies. Soft law should be combined with outside action that aims to remedy the existing system-wide accountability gaps for emerging environmental silver bullets.

In the case of emerging environmental silver bullets, soft law approaches to date have largely worked to reinforce the deployment of problematic technologies, instead of constraining them. A variety of factors motivate the development of private standards that govern the conduct of companies, from a desire to preempt formal regulation and promote self-governance, to a social goal of promoting public good outcomes. Very few of these incentives apply to the technological passion projects of wealthy oligarchs. As a result, there is no indication that the same PEG mechanisms that have come to dominate and constrain private sector environmental action will also evolve around environmental silver bullets. For instance, there are no voluntary standards being proposed to dictate what environmental technologies wealthy philanthropists should support. Instead, existing soft power-based organizations, like the World Economic Forum, often work to uncritically promote new environmental silver bullets.

A successful move to improve voluntary governance for emerging environmental silver bullets could hinge on creating standards or environmental impact assessment requirements for emerging technologies. These soft law options are defined by a permissive, ex-ante approach to solving environmental problems. However, allowing private actors and non-governmental bodies to dictate environmental standards can lead to outcomes that are preferred by private sector actors and may be too lenient to achieve public environmental goals. Nonetheless, if these impact assessments were made public, it would help to improve public accountability for technologies, even if substantive limits on action were unlikely.

Other options could focus on ex-post responses to any consequences that arise after deploying technological solutions. Addressing impacts after the fact has the benefit of clarity: while determining potential environmental impacts beforehand comes with significant uncertainty as to the type and magnitude of effects on complex ecosystems, once these impacts have happened it is much easier to target remedies directly to mitigate them. However, while

306. *See, e.g.*, Coglianese, *supra* note 25, at 48; Hagemann et al., *supra* note 25, at 40–42; Marchant, *supra* note 25, at 1866–68.

understanding the impacts may be easier after the fact, remediating environmental damage is notoriously difficult. What has been done cannot so simply be undone. Human impacts on the environment have ripple effects, and understanding and mitigating the extent of these cascading impacts in complex ecosystems is extremely difficult, if not impossible.[307] However, some have argued that NEPA would be more effective if instead of extensive ex-ante impact analysis, it required more stringent monitoring of impacts during the lifecycle of environmental projects.[308] Identifying negative impacts could allow real-time modification of activities to reduce environmental harms. Applying this approach to silver bullet technologies could help strike a balance between ex-ante and ex-post impact analyses.

Other, more creative mechanisms to increase accountability may be even more promising than prescriptive, NEPA-type environmental impact analysis approaches. Providing tools for organizations like the World Economic Forum, which currently champions many silver bullet technologies, to play a more critical role in assessing these technologies, could serve as an important check on ill-advised technology deployment. In other sectors, training requirements for technology developers have been suggested to influence technological outcomes in a more subtle way.[309] Applying these principles to environmental silver bullets could lead to governance measures that focus on altering the behavior of wealthy technology benefactors. In many cases, these individuals seek to gain social capital and positive media attention through their involvement in efforts to improve environmental conditions. Often, they work to enhance these outcomes through engagement with global powerbrokers like the World Economic Forum. One strategy to improve accountability for environmental silver bullets could be encouraging these gatekeepers to enhance accountability and vetting for technologies they champion.

Other strategies could hinge on increasing public awareness and scrutiny of environmental technologies. Unfortunately, silver bullets are the type of simple, if flawed, solutions that appeal easily to broad portions of the public. The public is not likely to apply sufficient scrutiny to these types of solutions.

Funding mechanisms can also provide some measure of accountability for emerging technologies. Public sector funding is the most effective at achieving these ends: NSF and other bodies are important funders of emerging technologies.[310] However, most funding for environmental silver bullets does not come from public sources, and private sector funding does not carry the same accountability.

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307. *See* J. B. Ruhl, *Governing Cascade Failures in Complex Social-Ecological-Technological Systems Framing Context, Strategies, and Challenges*, VAND. J. ENT. & TECH. L. 407, 436–39 (2019).

308. Karkkainen, *supra* note 299, at 931.

309. Moses, *supra* note 21, at 6.

310. *See, e.g.*, *Environmental Technologies*, NAT'L SCI. FOUND., https://seedfund.nsf.gov/topics/environmental-technologies/ (last visited Dec. 22, 2022) (showing environmental topics and companies that receive NSF funding).

CONCLUSION

Emerging technologies will be essential to combatting environmental challenges. Floating wind turbines, large-scale solar desalination, and gene drives to control invasive species are all already important pieces of our environmental management landscape. Fourth Industrial Revolution technologies provide new opportunities to tackle complex, large-scale environmental problems. With greater speed, larger scales, and increased accessibility, emerging technologies present a series of new and exciting tools for environmental governance. However, the private sector is much more able to capitalize on these technologies than the public sector. Existing processes to ensure accountability in government operations make the integration and regulation of rapidly emerging technologies notoriously difficult. As a result, most large-scale environmental technology interventions are happening outside of the public sector.

In the private sector, wealthy individuals are leading the development and deployment of large-scale environmental technologies. While many of these technologies have been touted for their ability to democratize environmental decision-making, in practice, those with the most resources are the most able to take advantage of these technological developments. The result is the current landscape of environmental technology—heavily driven by wealthy, amateur individuals who are intent on spurring rapid, system-wide change.

The combination of private sector actors, a suite of individuals that operate without the same environmental law constraints placed on governments, and emerging technologies, which often are not covered by existing environmental regulation at all, is creating fundamental challenges for environmental governance regimes. In many cases, large-scale technologies with significant negative consequences are deployed in governance gaps.

The consequences of these technology projects are large: environmental impacts from ecosystem disruptions are unpredictable and cascading. The scale of new technologies means that these impacts are not easy to contain, geographically or temporally. At the same time, placing the power to determine environmental outcomes in the hands of wealthy private sector actors undermines democratic notions and flies in the face of current movements towards recognizing environmental justice and participation as an essential feature of effective environmental governance.

As new silver bullets are proposed and deployed, scientists and policymakers respond with shrugs of resignation and sighs over the futility of these solutions. However, these solutions have quickly come to dominate public discourse and the funding landscape. Silver bullets not only have real and substantive environmental impacts, but they fundamentally change the narrative of environmental progress in ways that deserve engagement. Many environmental silver bullets will ultimately be self-correcting when it comes to their impacts. In the case of The Ocean Cleanup or the One Trillion Trees

Initiative, for instance, scientific skepticism and repeated failures have so far slowed the momentum of these technologies. However, even when environmental silver bullets fail, focusing on the technological solutions created and championed by a wealthy elite serves to widen existing environmental inequities. Our obsession with technological fixes ignores the reality that complex and difficult engagement with social-ecological systems is needed to make meaningful progress to mitigate environmental harm.

Going forward, both formal regulation and informal mechanisms are needed to create better accountability for large-scale environmental technology solutions. Despite the potential consequences, new technologies hold real promise for improving ecosystem health and environmental management globally. Many potential features could improve governance of these technologies, but it is essential that innovation be allowed to continue without being subject to stifling bureaucratic processes. Improving accountability for emerging technologies should be the cornerstone of new, flexible approaches to evaluate the risks and benefits of emerging technologies in the environment.

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