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Complexity in Global Energy-Environment Governance

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Climate change is a reality, growing in significance as the potential for rapid and severe disruption of ecological and social systems looms ever larger. Transformations such as ecosystem collapse, dramatic sea level rise, and a host of other disturbances of biophysical systems threaten social and economic stability. Against these risks, the world's governments have struggled in international negotiations to arrive at even the most modest and clearly insufficient agreements,[1] while the United States continues to lack protective environmental policies to limit greenhouse gas (GHG) emissions.[2] The need for a new approach is widely recognized[3] and exceptionally urgent. One promising avenue for developing such an approach lies in reconceptualizing climate change mitigation as an emergent property of the global energy system.

A growing body of legal literature has begun examining energy law—a field which evolved separately from, and has only occasionally been significantly constrained by, environmental law—in an effort to promote development of clean technologies that can ultimately help mitigate climate change.[4] The present Article also aims to promote renewable

1. *See infra* Part I.D.4.

2. *See, e.g.*, Hari M. Osofsky, *Diagonal Federalism and Climate Change Implications for the Obama Administration*, 62 ALA. L. REV. 237, 246–48 (2011) (providing a historical summary of U.S. climate change initiatives).

3. *See, e.g.*, INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2012 FACTSHEET 1 (2012) [hereinafter IEA FACTSHEET] ("Taking all new developments and policies into account, the world is still failing to put the global energy system onto a more sustainable path.").

4. For examples from U.S. legal literature, see JOSEPH P. TOMAIN, ENDING DIRTY ENERGY POLICY: PRELUDE TO CLIMATE CHANGE 233–34 (2011) ("Historically, energy and the environment were separate ways of viewing the

energy technology with a goal of climate change mitigation, but offers a different perspective than other recent U.S. legal scholarship oriented toward this goal. Rather than focusing on how the substance or structure of energy and environmental law could be modified, this Article reconceptualizes climate change in order to explore the potential for developing governance reforms that may rapidly advance mitigation goals by catalyzing a transformation of the global energy system. If climate change can appropriately be understood as a threat to global socio-ecological systems brought about by the configuration of the existing global energy system, viable solutions will be those that ultimately reconfigure the global energy system.

Drawing on complex systems theory,[5] particularly as it has been applied in the interdisciplinary socio-ecological systems literature and U.S. environmental law analysis, I suggest that climate change can be understood as an emergent property of the global energy system arising from a highly resilient system state in which fossil-fuel-based technology dominates and GHG emissions remain high. This perspective leads to policy recommendations for addressing climate change aimed at catalyzing a transformation of the global energy system to dislodge fossil fuel dominance and initiate large-scale diffusion of renewable energy technologies. Thinking of reforms in these terms offers hope, perhaps the last hope, for significant near-term mitigation on a global scale because it can avoid the major political challenges that have plagued environmental law

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world . . . . A smart energy future recognizes the interrelatedness of energy and environmental strategies."); Lincoln L. Davies, *Alternative Energy and the Energy-Environment Disconnect*, 46 IDAHO L. REV. 473, 491 (2010) ("Putting energy law and environmental law side by side yields an immediate contrast. The fields work toward different ends."); Uma Outka, *Environmental Law and Fossil Fuels: Barriers to Renewable Energy*, 65 VAND. L. REV. 1679, 1682 (2012) ("[A]n implicit support structure for fossil energy is written into . . . environmental law, and . . . inevitably distort[s] how the costs of bringing new energy technologies to scale are perceived."); Amy J. Wildermuth, *The Next Step: The Integration of Energy Law and Environmental Law*, 31 UTAH ENVTL. L. REV. 369, 381 (2011) (finding that "environmental law and energy law do very different work[;] [t]hey have different aims," as the former seeks to protect health and conserve resources while the latter promotes economic development); *see also* Hari M. Osofsky & Hannah J. Wiseman, *Dynamic Energy Federalism*, 72 MD. L. REV. 773, 829–31 (2013) (explaining the substantive overlap between environmental and energy law).

5. *See infra* Parts II, III.

approaches, including international treaty negotiations[6] and passage of comprehensive national legislation in the United States.[7] Instead, this approach involves identifying and changing components of the global energy system that may accrete, interact, and react in ways that magnify their impact, promoting a transformation toward an alternative, low-GHG trajectory of the system.

Although necessarily uncertain and tentative, this approach is neither wishful nor magical thinking, as it might at first appear to someone who has focused exclusively on linear and incremental policy reform. Instead, this approach applies widely recognized processes of complex systems, through which relatively small adjustments to components of the current system state can shift the momentum away from reinforcing the current state (fossil energy dominance) through adaptive processes and toward a fundamentally different system state (such as a renaissance of renewable energy technology).[8] The proposal is apparently novel in the legal literature,[9] but fits well with recent work in other disciplines, including a significant body of socio-technical systems research and

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6. *See infra* Part I.D.4.

7. *See supra* note 2 and accompanying text.

8. *See infra* Part II.

9. Research for this article did not uncover any articles by legal scholars or in legal journals discussing the approach to mitigation proposed here. Only English-language literature was searched, and U.S. legal literature was reviewed most thoroughly. Moreover, it is important to note that J.B. Ruhl has long suggested that complexity theory offers an important perspective on environmental law problems and the legal system in general. *See generally* J.B. Ruhl, *Complexity Theory as a Paradigm for the Dynamical Law-and-Society System: A Wake-Up Call for Legal Reductionism and the Modern Administrative State*, 45 DUKE L.J. 849 (1996) [hereinafter Ruhl, *Complexity Theory*]; J.B. Ruhl, *Thinking of Environmental Law as a Complex Adaptive System: How to Clean Up the Environment by Making a Mess of Environmental Law*, 34 HOUS. L. REV. 933 (1997) [hereinafter Ruhl, *Thinking*]. Other works suggest that energy policy must be understood as the context in which climate change should be addressed. *E.g.*, Susann Handke & Ellen Hey, *Climate Change Negotiations in a Changing Global Energy Landscape: A Wicked Problem*, 2 EUR. SOC'Y INT'L L. REFLECTIONS, Sept. 4, 2013, 1, http://www.esil-sedi.eu/sites/default/files/ESIL%20Reflections%20-%20Handke%20and%20Hey.pdf. One article, written contemporaneously with the present Article, suggests that the global energy system can be understood as a complex system. Frank A. Felder, *Climate Change Mitigation and the Global Energy System*, 25 VILL. ENVTL. L.J. 89 (2014). The present proposal may, therefore, be understood as a synthesis, rather than a truly novel proposal. Yet, "there is nothing new under the sun." *Ecclesiastes* 1:9.

nascent political science work developing a methodology for identifying appropriate components of legal and political systems to target in order to take advantage of path dependency characteristics and promote the emergence of more effective approaches to global environmental change.[10] The proposal may also find empirical support in case studies of smaller-scale energy system transformations, such as Brazil's move away from fossil energy in the 1970s.[11]

The analysis in the balance of this Article suggests that, at a minimum, the proposal has sufficient promise to warrant further research, as well as serious consideration by policy makers and advocacy organizations throughout the world. Part I highlights the failure of environmental law approaches to produce an effective international climate change mitigation response,[12] and offers a sketch of several major aspects of the global energy policy landscape that suggest its complexity. Part II briefly discusses complex systems theory as it has begun to influence environmental law scholarship. Part III makes explicit the claim that climate change can be understood as an emergent property of the global energy system and highlights complexity theory concepts to inform law and policy related to mitigation, noting particularly the importance of technology and the undesirable resilience of systemic properties related to climate change. Part IV concludes by offering some preliminary suggestions for design principles and operational approaches relevant to energy governance reform that could support a far more effective response to the mitigation challenge.

I. CLIMATE CHANGE, ENVIRONMENTAL LAW, AND GLOBAL ENERGY POLICY

From the early 1990s through 2009, the primary focus of efforts to address climate change was on the development of the United Nations Framework Convention on Climate Change (UNFCCC) regime.[13] The UNFCCC approach to climate change can be understood as a classic or traditional environmental law

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10. *See infra* Part III.B.
11. *See infra* note 260 and accompanying text.
12. *See infra* Part I.
13. *See* E. Lisa F. Schipper, *Conceptual History of Adaptation in the UNFCCC Process*, 15 REV. EUR. COMMUNITY & INT'L ENVTL. L. 82, 82, 85–88 (2006) (discussing the development of the UNFCCC).

response to an environmental problem.[14] The regime's goal is framed in environmental law terms of harm prevention—"to achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"[15]—and the means to do so were conceived in terms of quantifiable targets for the reduction of GHGs.[16] Further, most analysis under the regime was framed by the "conventional" economic theory of preventing a "tragedy of the commons," which emphasizes the need for a legally authoritative institution holding power to impose sanctions for non-compliance with binding rules.[17] As a degree of success was achieved in advancing this structure during negotiations toward the Kyoto Protocol, significant effort was devoted to developing "flexibility mechanisms" as a means of reducing overall compliance costs.[18]

The effort to develop international climate change law in UNFCCC negotiations drew on past environmental law successes—particularly the success of the 1987 Montreal

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14. Cinnamon P. Carlarne, *The Future of the UNFCCC: Adaptation and Institutional Rebirth for the International Climate Convention* 5 (Ohio State Univ. Moritz Coll. of Law, Working Paper No. 172, 2012), *available at* http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID2148438_code1468587.pdf?abstractid=2148438&mirid=2 (describing mitigation policies as the "business as usual" approach); *see also* William Boyd, *Climate Change, Fragmentation, and the Challenges of Global Environmental Law: Elements of a Post-Copenhagen Assemblage*, 32 U. PA. J. INT'L L. 457, 469 (2010) (describing how focus on stabilization targets is currently the "dominant approach to climate governance"); Schipper, *supra* note 13, at 82 (explaining that the UNFCCC process was intended to focus on reversing changes in climate by mitigating GHG emissions).

15. Schipper, *supra* note 13, at 86.

16. *See id.* at 84 ("[M]itigation focuses on the source of climate change . . . ."); Carlarne, *supra* note 14, at 5 (describing the UNFCCC and Kyoto Protocol as agreements that have adopted a "targets . . . approach to reducing global greenhouse gas emissions").

17. Elinor Ostrom, *Polycentric Systems for Coping with Collective Action and Global Environmental Change*, 20 GLOBAL ENVTL. CHANGE 550, 551 (2010) ("The conventional theory of collective action predicts . . . [that] an external authority is required to impose enforceable rules . . . . [There exists the] presumption that collective-action problems that have global effects must primarily be 'solved' by legal actions of a global authority . . . .").

18. *See generally* Michael Grubb, *Cap and Trade Finds New Energy*, 491 NATURE 666, 666 (2012) (discussing how the "cap-and-trade" model utilized in the Kyoto Protocol allowed countries a high level of flexibility in meeting reduction targets).

Protocol in addressing ozone depletion[19] and the Acid Rain Program of the 1990 U.S. Clean Air Act Amendments.[20] However, the model of regulation represented by those successful programs never fit well with the climate change problem.[21] Among other reasons, acid rain in the United States and global ozone depletion were both caused by a discrete and identifiable group of actors within developed countries, and technological fixes to the problematic substances were available (in the form of alternatives or pollution control devices), which meant that framing the problems in terms of harm prevention and compliance cost reduction was both accurate and effective.[22] Climate change, however, does not have either of

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19. *See, e.g.*, SEBASTIAN OBERTHÜR & HERMANN E. OTT, THE KYOTO PROTOCOL: INTERNATIONAL CLIMATE POLICY FOR THE 21ST CENTURY 282 (1999) ("[T]he Montreal Protocol has served . . . as a useful precedent and model for the [UN]FCCC and its Kyoto Protocol."); Schipper, *supra* note 13, at 86 (mentioning that emissions reduction strategies were effectively used in the Montreal Protocol).

20. The Acid Rain Program of the 1990 Amendments to the U.S. Clean Air Act is widely recognized as the first large-scale successful use of a cap-and-trade program. *See* Lesley K. McAllister, *Enforcing Cap-and-Trade: A Tale of Two Programs*, 2 SAN DIEGO J. ENERGY & CLIMATE L. 1, 4–9 (2010) (discussing the success of the Acid Rain Program). During climate change negotiations, in the words of one commentator, the United States "rammed a global cap-and-trade model into the Kyoto Protocol." Grubb, *supra* note 18, at 666. It appears that the success of the Acid Rain Program in cost effectively reducing emissions provided motivation for U.S. cap-and-trade proposals during Kyoto Protocol negotiations. Gwyn Prins & Steve Rayner, *Time to Ditch Kyoto*, 449 NATURE 973, 973 (2007) (suggesting that the design of the Kyoto Protocol was influenced by successful regulation of acid rain, ozone depletion, and nuclear proliferation in the 1980s).

21. *E.g.*, Scott Barrett, *Montreal Versus Kyoto: International Cooperation and the Global Environment, in* GLOBAL PUBLIC GOODS: INTERNATIONAL COOPERATION IN THE 21ST CENTURY 192, 192–219 (Inge Kaul et al. eds., 1999) (discussing the differing economic calculations affecting ozone and climate change negotiations); Handke & Hey, *supra* note 9, at 2 (observing that the UNFCCC regime approach to climate change was "inspired by" the Montreal Protocol, but noting that "[c]limate change does not fit the parameters of the ozone problem").

22. *See, e.g.*, Handke & Hey, *supra* note 9, at 2 ("The Montreal Protocol was highly successful, as economically viable alternatives were available for removing ozone-depleting gases from a limited number of products and production processes."); McAllister, *supra* note 20, at 4–8 (summarizing the reasons for the success of the Acid Rain Program, including highly effective emissions monitoring and enforcement policies).

these characteristics.[23] Instead, attempts to impose quantifiable GHG emissions reduction targets raised deep equity issues between developed and developing countries,[24] while also posing a challenge that implicated the prospect of requiring major changes across a wide range of economic sectors (such as energy and transportation) without any clear technological means of accomplishing them.[25]

The 2009 UNFCCC negotiations in Copenhagen marked a decisive end of the collective illusion that a top-down, legalistic model of the Kyoto Protocol could provide the authority envisioned by "tragedy of the commons" metaphors.[26] Since then, scholars and policymakers have searched for alternative means of addressing climate change by searching for lessons in the failures of the UNFCCC process and by seeking alternative approaches.[27]

A. Energy Policy as a Context for Climate Policy

One lesson from the failed UNFCCC efforts, which drives much of the current interest in melding environmental and energy law, is that *context matters*. As Elinor Ostrom noted, "[t]here are no panaceas . . . for complex problems such as global warming."[28] The Montreal Protocol worked in the context of ozone depletion and the Acid Rain Program worked

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23. *E.g.*, Handke & Hey, *supra* note 9, at 2 ("Climate change does not fit the parameters of the ozone problem. Thus far, there are no generally accepted solutions let alone implementation paths.").

24. *See id.* at 6 ("Implementing these agreements will require an unprecedented level of cooperation . . . especially between the industrialized world and emerging market powers. These efforts will have to go far beyond the current stalemated negotiations between developed and developing states."); *see also* David Tackacs, *Forest Carbon Offsets and International Law: A Deep Equity Legal Analysis*, 22 GEO. INT'L ENVTL. L. REV. 521 (2010) (proposing a concept of "deep equity" that is similar to the meaning implied here).

25. *See* Handke & Hey, *supra* note 9, at 2, 5 (arguing that policies going forward will "alter fundamental structures of our economy," while highlighting the notion that we currently have no generally accepted technological means in place to implement new climate change policies and that "new technologies and energy markets occasionally . . . lead to 'backward' fuel choices").

26. *See* Dale Jamieson, *Climate Change, Consequentialism, and the Road Ahead*, 13 CHI. J. INT'L L. 439, 444, 448–54 (2013) (examining "The Dream of Rio" as a force-shaping climate policy and its end at the 2009 negotiations in Copenhagen).

27. *See infra* Parts I.A–D, III.

28. Ostrom, *supra* note 17, at 555.

in the context of the U.S. acid rain problem, but they did not create one-size-fits-all prescriptive models.[29] Addressing climate change will require attention to the context in which the problem arose and the development of contextually appropriate strategies to change the behaviors causing the problem.[30]

There are essentially two policy areas that constitute the contexts from which climate change arose: energy and land use (primarily deforestation).[31] Each context raises its own unique issues, opportunities, and challenges. This Article's scope examines energy, but there is one point worth noting about deforestation. Somewhat ironically, while deforestation received relatively little attention through the UNFCCC regime, it has been the area of greatest agreement in recent negotiations[32] and produced an innovative REDD+[33] program that some, including myself, have suggested may hold clues as to what more effective forms of climate regulation on a global scale might look like.[34] In line with the argument below, this recent progress may be a result of the rather broad and flexible principles that have framed discussions addressing deforestation in the climate change regime, which have fostered a wide range of innovative governance experiments at multiple scales.[35] Energy-based mitigation, by contrast, was

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29. *See supra* note 22.

30. *See* Handke & Hey, *supra* note 9, at 1–2 (suggesting that pre-existing international efforts proceeded "without an agreed context" and suggesting that "energy policy has to be a starting point if we wish to mitigate climate change").

31. *See* Boyd, *supra* note 14, at 458, 523–27 (looking at the recent emergence of deforestation as "a major focus of climate policy" and the impact of deforestation on global carbon emissions); Handke & Hey, *supra* note 9, at 4 (discussing the difficulties in energy regulation due to the "current structure of the energy sector" and global reliance on fossil fuels).

32. Boyd, *supra* note 14, at 458 ("[D]eforestation . . . has only recently become a major focus of climate policy, emerging as one of the few areas of consensus in the international climate negotiations.").

33. REDD refers to reduced emissions from deforestation and forest degradation.

34. *E.g.*, Boyd, *supra* note 14, at 471–73; Andrew Long, *Global Climate Governance to Enhance Biodiversity & Well-Being: Integrating Non-State Networks and Public International Law in Tropical Forests*, 41 ENVTL. L. 95, 163 (2011) ("Thus, the convergent legal mechanism suggested here for REDD could be developed into a novel approach to multiple areas of global environmental governance.").

35. *E.g.*, Boyd, *supra* note 14, at 549–50.

the subject of the most intensive, rigid, and detailed legal and institutional development of the UNFCCC.[36] Stepping back from the narrow focus of the UNFCCC, however, we can see that the primary features of the energy context that are directly relevant to climate change are fossil fuel dominance and the global scale of energy-related forces (including market forces) that shape the policy arena.[37] Indeed, fossil fuel dominance of the energy sector is the single most important reason for climate change risks.[38]

B. CLIMATE CHANGE: ENVIRONMENTAL HARM FROM AN ENERGY PROBLEM

Climate change remains a major threat to humanity primarily because GHG emissions are increasing,[39] while a robust scientific consensus has developed around the need for dramatic decreases over the near-term in order to stabilize the climate system.[40] It would be hard to overstate the severity of the problem. Global energy demand is rising dramatically and, even assuming rapid development of renewables, the present energy policy structure would meet approximately seventy-five

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36. *E.g.*, Schipper, *supra* note 13, at 82–83.

37. *E.g.*, Handke & Hey, *supra* note 9, at 5 ("Given the dominance of fossil fuels, the implementation of bold climate measures will cause severe financial and economic disruptions, as fossil-fuel based facilities worth hundreds of billions would become 'stranded assets' and the use of renewables involves much higher costs. Thus, government policies towards the energy sector have great impact on the future global energy landscape and international climate governance.").

38. *Cf.* IEA FACTSHEET, *supra* note 3, at 1.

39. *E.g.*, Howard Bamsey & John Christensen, *Foreword* to UNEP RISØ CENTRE, ELEMENTS OF A NEW CLIMATE AGREEMENT BY 2015, at 4, 4 (Karen Holm Olsen et al. eds., 2013) (finding that a comparison of UNEP's 2011 and 2012 reports "indicate[ ] that global emissions are increasing").

40. A number of recent studies analyze the extent of emissions reductions needed to stabilize the climate system at a level of global average temperature rise consistent with the two degrees Celsius goal established by UNFCCC negotiations. *See*, *e.g.*, Michel G.J. den Elzen et al., *Analysing the Greenhouse Gas Emission Reductions of the Mitigation Action Plans by Non-Annex I Countries by 2020*, 56 ENERGY POL'Y 633, 633 (2013) (concluding that, in order to stabilize the climate at two degrees Celsius above the baseline, developed countries would need to reduce emissions by fifty percent below 1990 levels by 2020 if developing countries meet their current pledges); *see also* Bamsey & Christensen, *supra* note 39, at 4 (providing several analyses of "crucial aspects" required to meet stabilization goals).

to eighty percent of the demand with fossil fuels.[41] The International Energy Agency (IEA) estimates that even with a significant shift away from coal and oil, anticipated emissions through 2035 correspond with a long-term global average temperature rise of 3.6 degrees Celsius.[42] The Intergovernmental Panel on Climate Change (IPCC) and others predict major impacts on human health and natural systems at that level of temperature change.[43] For example, that degree of climate change is likely to cause many terrestrial ecosystems, such as the Amazon Rainforest, to undergo dramatic transformation, if not collapse.[44] Such transformation will not only rapidly accelerate biodiversity loss and undermine human well-being in the region, but also have implications for hydrological cycles while transforming terrestrial ecosystems into a net source of GHGs as they undergo fundamental transformations, thus further accelerating climate change.[45] In

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41. DRIES LESAGE ET AL., GLOBAL ENERGY GOVERNANCE IN A MULTIPOLAR WORLD 2 (2010) ("[E]nergy demand is set to rise spectacularly in the coming decades, especially in the emerging and developing world. Without policy adjustments, global energy demand will increase by over 50 percent by 2030, and up to 80 percent of this demand will be met by fossil fuels." (citation omitted)); *see also* IEA FACTSHEET, *supra* note 3, at 1 (stating that fossil fuels currently represent eighty-one percent of the global energy market, and will only drop to a seventy-five percent share by 2035).

42. *Cf.* IEA FACTSHEET, *supra* note 3, at 1 (anticipating natural gas to nearly overtake coal as an energy source by 2035, by which time rise in energy-related CO_2 emissions will have led to a long-term average temperature increase of 3.6 degrees Celsius).

43. For example, the IPCC estimates a loss of approximately thirty percent of coastal wetlands, significant disruption of food production, and the net transformation of ecosystems from carbon sinks to carbon sources at temperature increases of more than three degrees Celsius. M.L. PARRY ET AL., CONTRIBUTION OF WORKING GROUP II TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE: SUMMARY FOR POLICYMAKERS 11–12, 16 (2007), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf.

44. Chris Jones et al., *Committed Terrestrial Ecosystem Changes Due to Climate Change,* 2 NATURE GEOSCIENCE 484, 485 (2009), *available at* http://www.nature.com/ngeo/journal/v2/n7/pdf/ngeo555.pdf ("There seems to be a temperature below which the equilibrium state of the [Amazon] forest is approximately constant, but above which the equilibrium forest cover declines steadily with changing climate. This point could be seen as a threshold beyond which some degree of loss of Amazon forest is inevitable.").

45. *See id.* at 484–86 (using modeling to demonstrate committed ecosystem damage in the Amazon that would result from increasing global temperatures); *see also* PARRY ET AL., *supra* note 43, at 11–16 (discussing the impacts of climate change on ecosystems and human health). Recent droughts

short, projections of the energy system over the coming decades suggest that GHG emissions will continue at such a level that climatic changes will dramatically increase human suffering in some parts of the world,[46] cause significant and disruptive impacts on natural systems (many of which are largely unpredictable),[47] and impose significant economic stress on even the world's most robust economies.[48]

Although climate change may be most familiar to us as an environmental problem, this does not necessarily mean that it will be most effectively regulated through environmental law techniques. Climate change is part ecological concern, particularly through its natural processes and impacts, and part economic concern, particularly through its causes in the energy sector.[49] Thus, there are at least two ways to approach regulation—one focused on the ecology of climate change and one focused on the economy of climate change. The former suggests an approach derived from working backwards from a desired result in natural systems;[50] the latter suggests an

in the Amazon region are affecting a significant portion of the forest, which may suggest that climate change is already impacting the ecosystem. *E.g.*, Jonathan Watts, *Amazon Showing Signs of Degradation Due to Climate Change, NASA Warns*, THE GUARDIAN (Jan. 18, 2013, 11:33 AM), http://www.theguardian.com/environment/2013/jan/18/amazon-rainforest-climate-change-nasa.

46. *See* PARRY ET AL., *supra* note 43, at 13 ("Agricultural production, including access to food, in many African countries and regions is projected to be severely compromised by climate variability and change.").

47. *See id*. at 8–11 (highlighting the impacts of climate change on ecosystems and natural systems).

48. Lesage et al. suggest possible global depression given the importance of fossil fuels in the world economy, for example, and note that Stern has suggested climate change could impose economic costs equivalent to a five to twenty percent reduction of consumption per person, LESAGE ET AL., *supra* note 41, at 2, which is not to say it would be evenly distributed, of course.

49. *See generally* MALTE FABER & REINER MANSTETTEN, PHILOSOPHICAL BASICS OF ECOLOGY AND ECONOMY 16–24 (Dale Adams trans., 2010) (providing that the disciplines of ecology and economics "lay the foundation for environmental education").

50. *See* MICHAEL COMMON & SIGRID STAGL, ECOLOGICAL ECONOMICS: AN INTRODUCTION 506–10 (2005) (analyzing a potential, yet unrealistic, ecological approach to climate change in the context of setting mitigation targets and working backwards from the mitigation targets to determine how to effectively achieve them).

approach based on the human systems that have caused the disturbances in the natural systems.[51]

The two words, "ecology" and "economy," suggest the differences in ecological and economic approaches to climate change mitigation. Their common root "eco," which derives from the Greek word *oikos* ("house"), reflects that both involve a form of "house-keeping."[52] The suffixes of "ecology" and "economy" reveal their differences. "Ecology" includes a suffix derived from the Greek word *logos* ("study") and thus reflects a "house-keeping" based on studying the entire planet, the relationships of all organisms and processes that make up our "home," the Earth.[53] "Economy," on the other hand, includes a suffix derived from the Greek word *nomos* ("order") and thus reflects a "house-keeping" of order created by humanity, the management of human organization and interaction, rather than a pre-existing natural system.[54]

Although overlapping and interdependent, ecological and economic approaches to climate change mitigation can be distinguished by the number of actors involved. Ecological systems involve a myriad of living and non-living types of actors or forces, while humans alone are the primary actors in economic systems.[55] Thus, an ecological approach will operate from a broad consideration of all relevant processes and components, such as the environmental law approach focused

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51. *See id.* at 1–3, 12 ("The global scale of human economic activity is now such that the levels of its extractions from and insertions into the environment do affect the way that it works.").

52. For this and related points, I am indebted to Jim Chen's feedback on an earlier draft of this article. Jim discusses "house-keeping" in Jim Chen, *Biolaw: Cracking the Code*, 56 KAN. L. REV. 1029, 1031–32 (2008); *see also, e.g.*, FABER & MANSTETTEN, *supra* note 49, at 16 ("The special significance of ecology and economics is revealed as soon as we take a closer look at the two terms themselves: 'ecology' and 'economy'. Both share the component 'eco' which is derived from the ancient Greek word 'oikos', meaning 'house'. Oikos does not only mean the building itself, however, but refers to everything that can be better summarised [sic] under the term 'household'.").

53. *E.g.*, COMMON & STAGL, *supra* note 50, at 1 ("Ecology is the study of nature's housekeeping . . . ."); FABER & MANSTETTEN, *supra* note 49, at 18–20.

54. *E.g.*, FABER & MANSTETTEN, *supra* note 49, at 16–18; *see also* COMMON & STAGL, *supra* note 50, at 1 ("[E]conomics is the study of housekeeping in human societies.").

55. COMMON & STAGL, *supra* note 50, at 1.

on harm prevention.[56] An "economic" approach in this sense, however, will focus more directly on the human-created order that gives rise to the climate change problem and, thus, establish goals that seek to adjust the inputs and ordering of human relations more than achieving a pre-defined outcome.[57] Although either approach might be equally effective if fully implemented, the difference in orientation may have profound effects on the likelihood that either approach will be adopted and effectively implemented. The UNFCCC experience illustrates the challenge of employing an ecological approach to regulation of complex global environmental problems—it often seems as though the actors in climate debates spend more time identifying processes and the goals of regulation than on developing effective mechanisms to change the human behavior causing the problem.[58]

An "economic" approach, as that term is used here (which is explicitly not an endorsement of relying on markets), may be more successful simply because it focuses almost exclusively on human behavior, which (unlike ecosystem behavior) can be altered directly by adjusting rules, changing incentives, and employing other tools of regulation.[59] Thus, while climate change can be approached from several regulatory angles, energy policy—concerned primarily with the economics of converting resources into forms of energy suitable for human use—may provide a more promising avenue than environmental law.

While this initial argument for adopting an "economic" approach to climate change through a focus on the energy system relies on its relative simplicity, when compared with a more holistic ecological approach, the next Part will shatter any illusion that energy policy reform is a simple matter.[60] Although focusing primarily on energy policy may avoid many of the complications inherent in a broader focus on the impacts of climate change, energy policy itself poses a host of challenges to effective regulation, not the least of which is its complexity.

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56. *E.g.*, FABER & MANSTETTEN, *supra* note 49, at 19–20 ("Ecology is the science of the interactions of living creatures with one another and the abiotic conditions within their environments.").

57. *E.g.*, *id.* at 16–24.

58. *See infra* Part I.D.4.

59. *E.g.*, FABER & MANSTETTEN, *supra* note 49, at 20–23.

60. *See infra* Part I.D.

That, perhaps, is the strongest argument for focusing primarily, if not exclusively, on the "economic" order of energy policy in pursuing mitigation—once the goal of climate change mitigation has been accepted, there is no need to layer the complicating factors of environmental law approaches on top of the already complex challenge of energy system reform.

C. GLOBAL ENERGY POLICY AS THE CONTEXT FOR CLIMATE CHANGE MITIGATION

If energy policy is understood as the appropriate context for addressing climate change, the next question is whether the appropriate scale of reform efforts is national or global.[61] Recent U.S. energy law and policy scholarship addressing climate change seems to focus on U.S. domestic policy.[62] Unlike much of this recent literature, this Article identifies *global* energy policy as a context for climate governance.[63]

Articulating a reason to target U.S. energy policy, Joseph Tomain suggests that "difficulties in bringing together all nations in an effort to craft a climate change response [means that] . . . . the prelude to the United States taking an international leadership role is that domestically, it must take seriously the need to put in place a low-carbon energy economy."[64] However, Tomain also suggests that "we must create future energy policy as a transformative moment, not simply as an incremental transition moving slowly away from

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61. Other scales are, of course, possible. A related question is the extent to which reform should focus on encouraging individual behavior changes or to concentrate primarily on changing energy sources and other systemic factors. *Compare* Daniel A. Farber, *Sustainable Consumption, Energy Policy, and Individual Well-Being*, 65 VAND. L. REV. 1479, 1523 (2012) ("[P]olicymakers should give people the basis for making more informed, sustainable consumption decisions, both about their direct energy use and about goods such as water and food that require energy expenditures."), *with* Wildermuth, *supra* note 4, at 384 (describing individual voluntary actions as "far too little and far too late," and noting the relative difficulties of using this approach to bring about significant change in emissions).

62. I have not systematically compared the volume of literature on international and domestic policy, but research for this Article and related projects suggests that U.S. environmental law scholars give significantly more attention to domestic energy policy than to its larger-scale counterparts.

63. *See supra* note 9.

64. TOMAIN, *supra* note 4, at 232.

fossil fuels to new resources."[65] Although one can debate whether a transformational *moment* is strictly necessary, rapid transformation of energy practices would clearly provide greater climate benefits than a slower, linear process of incremental change.[66] In my opinion, the urgency of climate threats offers at least a preliminary reason to focus primarily on developing responses to climate change at the global, rather than national, scale. Attempting to improve U.S. energy policy as a prelude to international negotiations is, itself, an incremental approach in which each of the steps could take decades to complete—decades during which developing country emissions, in particular, are nearly certain to rise rapidly.[67] Changes to global energy policy, on the other hand, have at least the potential to reach a far larger share of total emissions than any single nation's policy and offers the option of targeting the massive growth in developing country emissions as an avenue for relatively rapid action (and relatively cost-effective) on emissions.[68] Thus, the potential for truly transformational change appears greater at the global scale.

The unwieldiness of international politics and the challenges of international law-making (as suggested by Tomain) likely explain why some scholars focus on domestic

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65. *Id*. at 234. A variety of views on this point are expressed in the literature. *See* Davies, *supra* note 4, at 506 ("Change, especially big change, takes time."); Farber, *supra* note 61, at 1523 ("Change will be slow, but practical first steps do exist."); Outka, *supra* note 4, at 1681 ("This Article is concerned with renewable energy's too-slow transition and with how existing legal regimes work to preserve fossil energy dominance."). Nonetheless, there is no serious debate over whether a transformation is necessary to address climate change or that delay increases the risks posed by climate change. *See supra* note 3 and accompanying text.

66. *E.g.*, Outka, *supra* note 4, at 1680–83.

67. *See* TOMAIN, *supra* note 4, at 232 (previewing the steps that the United States must put in place to improve domestic energy policy); *see also* Elzen et al., *supra* note 40, at 633 ("There are upward revisions of greenhouse gas emission projections in many developing countries.").

68. The projected growth in energy demand in developing countries is clearly justifiable to the extent it meets important social objectives associated with energy policy, such as relieving energy poverty. *See* Ann Florini & Benjamin K. Sovacool, *Bridging the Gaps in Global Energy Governance*, 17 GLOBAL GOVERNANCE 57, 66 (2011) ("Improved access to energy services is arguably the key defining characteristic of economic development."). Where basic access to electricity is the motivation for capacity additions, financing to support renewable technologies is likely to have a particularly direct effect in lowering emissions. *See id*. at 66–67.

policy despite the glaring need for global reform.[69] While it is true that global policies have the potential to affect emissions throughout the world, there seems to be a greater certainty that efforts will have at least some effect in domestic law—it is more predictable, and actors are subject to the jurisdiction of the United States, unlike the traditional actors in international law (sovereign states who can only be bound by their own consent).[70] International political actors now clearly include corporations, civil society organizations, and others who undoubtedly complicate the field,[71] which may seem to make global energy policy a particularly unappealing space for legal scholars used to working in areas where lines of authority and jurisdiction are, if not clear, at least comprehensible. The unpredictability of the global political environment may seem to make global policy reform as a strategy for climate change regulation a riskier bet and, thus, one might prefer the small but relatively certain progress that can be achieved with domestic law reform.[72]

However, this apparent argument for seeking predictability in a smaller-scale context should be turned on its head. The very complicated and, more importantly, *complex* context of governing at the global scale offers a key reason for scholars, and ultimately policymakers, to focus their energies on developing approaches that draw upon the interactions that characterize complex social and economic systems to unleash, or perhaps just nudge, the forces that drive complex systems toward inventing new pathways. These new pathways could be capable of re-orienting the energy system onto a trajectory that produces a low-carbon energy system far more rapidly than is conceivable through incremental, domestic-first strategies or the pre-existing track of UNFCCC negotiations.[73]

Maintaining a global focus in light of UNFCCC failures, rather than retreating to familiar domestic law and policy challenges with far less potential impact, forces us to change

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69. *See infra* Part I.D.4; *see also* TOMAIN, *supra* note 4, at 232 ("Copenhagen 2009, however, demonstrated the difficulties in bringing together all nations in an effort to craft a climate change response.").

70. *See* TOMAIN, *supra* note 4, at 234–35 (providing a number of principle and policy suggestions for domestic energy policy).

71. *See infra* Part I.D.4.

72. *E.g.*, TOMAIN, *supra* note 4, at 232, 234–35.

73. *See infra* Parts II, III.

the way we think of the mitigation challenge and may thereby reveal opportunities that are not available by adding up a collection of component domestic environmental efforts.[74] Climate change is a global phenomenon. This fact does not undercut the need for attention to smaller scales, but it does suggest that we should develop a multiscalar strategy that includes a well-crafted global element (rather than a vague hope for more effective negotiations if the United States gradually reduces its emissions) capable of spurring the types of interactions among reform efforts at all scales to produce the necessary transformative global change as quickly as possible. Examining energy policy on the global scale has the advantage of allowing us to consider that interaction of components within the undeniably global system that causes climate change, thus calling attention to an array of possibilities for reinventing global climate governance that cannot be seen when one focuses on the domestic level. Before elaborating on the ways in which focusing on the global energy system affects analysis of mitigation strategy in Parts II through IV, it is useful to briefly survey the terrain of global energy policy to elucidate some of its components.

D. CHALLENGES AND COMPLEXITIES OF THE ENERGY POLICY ARENA

Any hope to stabilize the climate system in the next few decades without resorting to geoengineering will be a rapid shift away from fossil-fuel dependent technologies on a large scale.[75] The technological and economic challenges of achieving this shift are enormous.[76] For example, the IEA reports that

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74. This has begun to happen in the context of forestry-related GHG emissions. *See* Boyd, *supra* note 14, at 470–73 (discussing REDD+ as perhaps the best example of the type of "assemblages" needed to address global environmental problems, such as saving the tropical rainforests); Long, *supra* note 34, at 162–64 (discussing the potential for REDD+ to stimulate more holistic environmental protection mechanisms). Relatively little literature discusses reconceptualizing the energy mitigation challenge, however. For an example, see David M. Driesen & Amy Sinden, *The Missing Instrument: Dirty Input Limits*, 33 HARV. ENVTL. L. REV. 65, 109–16 (2009) (discussing the framing of climate-energy problems).

75. *See* Felder, *supra* note 9, at 95–97 (stating that stabilization of GHG emissions in the next few decades would require "a complete overhaul of the existing and proposed [global energy system]").

76. *E.g.*, Cass R. Sunstein, *Of Montreal and Kyoto: A Tale of Two Protocols*, 31 HARV. ENVTL. L. REV. 1, 5–6 (2007) (stating that perceptions of

the *additional* electricity capacity required by 2035 is larger than the entire installed capacity of the world in 2011.[77] Much of this added capacity is predicted to be fossil fuel dependent, even with current and reasonably likely future renewable energy promotion policies taken into account.[78]

Moreover, many aspects of the existing energy system are socially reinforced through current legal, political, and institutional arrangements.[79] Thus, the absence of scalable and reliable alternatives to fossil fuels, in the context of rising demand for energy, combines with these factors to create a global energy system in which fossil fuels are becoming more deeply entrenched as the dominant energy source over exactly the period in which rapid decrease of GHG emissions is needed.[80]

The remainder of this Part highlights several of the most prominent aspects of the global energy policy arena that pose obstacles to significant reform. Perhaps the most prominent

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the high costs of compliance with the Kyoto Protocol, and of relatively low benefit, provide "the central explanation" for why that agreement was less successful than the Montreal Protocol); *see also* Barrett, *supra* note 21, at 200–16 (advancing a similar argument and providing detailed discussion of specific projections); Benjamin K. Sovacool, *Rejecting Renewables: The Socio-technical Impediments to Renewable Electricity in the United States*, 37 ENERGY POL'Y 4500, 4503 (2009) (explaining that implementing renewable power technologies challenge the existing energy system, and that the "process of creating and adopting technologies is complex, interactive, and political").

77. IEA FACTSHEET, *supra* note 3, at 3 (noting that this would include necessary replacement of existing capacity due to age).

78. *Id.* (expecting renewables to represent only half of the capacity additions).

79. *See, e.g.*, Rosemary Lyster, *Renewable Energy in the Context of Climate Change and Global Energy Resources* 1 (Sydney Law Sch., Legal Studies Research Paper No. 13/61, Aug. 2013), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2315911 (listing a number of significant barriers to the development of "renewable energy technologies"); Osofsky & Wiseman, *supra* note 4, at 780–807 (examining the impact of physical, market, and regulatory forces on the U.S. energy system); Sovacool, *supra* note 76, at 4501 (demonstrating that the "impediments to renewable power" are "socio-technical," encompassing "technological, social, political, regulatory, and cultural aspects").

80. *See* Felder, *supra* note 9, at 105 ("The GES is a large-scale system in which no single, carbon-free, or scalable technology exists that would stabilize greenhouse gas emissions in the relatively near future. It is an interconnected and open system, providing vital services in and of itself, but also to other complex systems such as transportation, communication, water, and security."); Lyster, *supra* note 79, at 17–18 (stating that fossil fuels are likely to remain dominant).

consideration in energy policy is economics.[81] As a primarily economic activity, one can argue that energy production is driven largely by the market. However, as discussed below, the energy market is severely distorted by subsidies, illustrating that fossil fuel dominance is not purely an economic matter.[82] Other considerations, including the very diffuse nature of authority exercised over energy decisions at the international level, complicate efforts to reform international energy policy.[83] Thus, after briefly touching on economic considerations that inhere to support the status quo, this Article highlights the roll that energy plays at the nexus of several other social and environmental issues, emphasizes the importance of energy in geopolitical power distribution, and describes the existing international energy governance structure, before subsequent Parts explore how these illustrative elements of global energy policy support conceptualizing climate change as an emergent problem of the global energy system.

1. Economics and Energy Policy

As is widely recognized, economic considerations maintain fossil fuel dominance in significant ways. Most obviously, many investments in energy generation are sunk costs that cannot be transferred or reinvested into another product or process.[84] For example, construction of an electricity generating facility entails large up-front costs and relatively low operating costs.[85] Accordingly, basic economic analysis encourages owners to operate the facility until the costs of maintenance justify constructing a new facility, effectively entrenching fossil fuel generation at the facility for decades.[86] However, isolating the role of economic considerations in this way risks providing a false picture of energy system dynamics.

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81. *See infra* Part II.D.1.

82. *See* Florini & Sovacool, *supra* note 68, at 64 (explaining that long-established subsidies that benefit fossil fuels and nuclear energy pervert the market and discourage the pursuit of alternative energy).

83. *See infra* Part II.D.4.

84. Felder, *supra* note 9, at 99 ("Much, if not all, of the initial investment in energy assets are sunk, that is, irreversible."); Sovacool, *supra* note 76, at 4504–06.

85. Felder, *supra* note 9, at 99–100.

86. *See id*. at 100–01.

Economic considerations favoring fossil fuel technologies are reinforced (perhaps even constructed) politically, most directly through fossil fuel subsidies that have proven exceptionally difficult to change.[87] Collectively, states provide as much as $700 billion in one year to economically support fossil fuel production and consumption.[88] These subsidies distort the market and affect the global political economy of energy.[89] The contrast between fossil fuel subsidies and renewable energy subsidies is stark: IEA estimates that 2011 combined global subsides for all renewable energy sources amounted to $88 billion, while fossil fuel subsidies were six times higher at $523 billion.[90] Despite repeated pledges by some of the world's most powerful nations to begin reducing fossil fuel subsidies, and even some modest action on those pledges, the overall level of fossil fuel subsidies rose thirty percent from 2010 to 2011.[91]

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87. *See* Lyster, *supra* note 79, at 17–18 (stating that reforming fossil fuel subsidies would significantly reduce GHG emissions, but that because of the inbuilt subsidies to fossil fuels and "the failure to fully internalize the climate and non-climate externalities," fossil fuels are likely to continue being our primary energy source).

88. The figure of $700 billion is an estimate of total fossil fuel subsidies in 2009 reported in the IEA, Organization of the Petroleum Exporting Countries, Organization for Economic Co-operation and Development (OECD), and World Bank Joint Report. INT'L ENERGY AGENCY ET AL., ANALYSIS OF THE SCOPE OF ENERGY SUBSIDIES AND SUGGESTIONS FOR THE G-20 INITIATIVE 4 (2010) [hereinafter G-20 JOINT REPORT], *available at* http://www.oecd.org/env/45575666.pdf. The Global Subsidies Initiative (GSI), an international civil society organization, estimates $600 billion in fossil fuel subsidies, including $100 billion in producer subsidies during the same year. *Fossil Fuels - At What Cost?*, GLOBAL SUBSIDIES INITIATIVE, http://www.iisd.org/gsi/fossil-fuel-subsidies/fossil-fuels-what-cost (last visited Mar. 3, 2014). However, GSI also notes that the actual value of subsidies is impossible to determine because there is no international monitoring framework in place. *Id.* In any event, the annual amount of fossil fuel subsidies fluctuates widely based on energy prices, economic activity levels, and other factors. G-20 JOINT REPORT, *supra*, at 4, 15.

89. *See* Florini & Sovacool, *supra* note 68, at 64 ("These subsidies distort the price signals that consumers receive . . . and artificially create demand for both energy and its associated infrastructure."); Lyster, *supra* note 79, at 12–13 (discussing various fossil fuel subsidies that make it difficult for renewable sources to compete "in terms of price").

90. INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2012, at 49, 66 (2012); Lyster, *supra* note 79, at 3–5 (discussing the IEA WORLD ENERGY OUTLOOK 2012).

91. IEA FACTSHEET, *supra* note 3, at 1 ("Subsidies to fossil fuels continue to distort energy markets and expanded considerably last year despite

Moreover, changing subsidy policies is not simply a matter of reforming developed countries' support for multinational energy corporations. In some countries, consumer subsidies—subsidies that effectively reduce the price of fossil fuels for the end consumer—are employed by national regimes to maintain popularity or diffuse public resistance to their rule.[92] Countries such as Russia, China, and Iran pour significant percentages of their GDP (worth billions of U.S. dollars) into subsidizing fossil fuels.[93] These subsidies have created political situations in which change can provoke volatile responses.[94] In Nigeria, for example, a decision to rapidly end fossil fuel subsidies resulted in rioting in the streets and a hasty reinstatement of the repealed policies.[95]

2. Social and Environmental Issues in Energy Policy

Global energy policy is also a node of connection many of the major global social and environmental issues that are likely to define the twenty-first century.[96] The social and environmental impacts of globally relevant economic variations in the energy system can be very large, as evidenced by the effects of oil price fluctuation on economies throughout the

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international efforts at reform."); INT'L ENERGY AGENCY, *supra* note 90, at 71 ("G-20 and [Asia-Pacific Economic Cooperation] member economies have made commitments in recent years to phase out inefficient fossil-fuel subsidies.").

92. *See* INT'L ENERGY AGENCY*, supra* note 90, at 70 (explaining that due to fossil fuel subsidies, consumers "paid only 76% of the reference or unsubsidized price," and that subsidies thus "reduce end-user prices below those that would prevail in an open and competitive market").

93. The economic value of fossil fuel consumption subsidies for Iran exceeded $80 billion in 2011, while Russia's was close to $40 billion and China's exceeded $30 billion. *Id.* at 71.

94. James Kanter, *Cost of Subsidizing Fossil Fuels Is High, But Cutting Them Is Tough*, N.Y. TIMES, Oct. 23, 2011, http://www.nytimes.com/2011/10/24/business/global/cost-of-subsidizing-fossil-fuels-is-high-but-cutting-them-is-tough.html ("These subsidies are fiendishly difficult to dismantle because of the political risks involved.").

95. Monica Mark, *Nigeria Reels After Oil Subsidy Row Turns into Country's Biggest Ever Protest*, THE GUARDIAN (Jan. 18, 2012, 1:38 PM), http://www.theguardian.com/world/2012/jan/18/nigeria-power-struggle-protest-oil; *see also* Kanter, *supra* note 94 (citing an example from Bolivia).

96. As Florini and Sovacool explain, energy issues "form a common thread across many of the most pressing global problems, cutting across geopolitical, environmental, and economic dimensions." Florini & Sovacool, *supra* note 68, at 57.

world.[97] Social impacts emerging from the current state of the energy system penetrate deeply in locally and globally significant ways.[98] Although climate change may well be the most important long-term social and environmental challenge of energy policy, there are a host of other major social and environmental concerns to confront, such as widespread health impacts from air pollution (especially in developing countries),[99] severe economic impacts resulting from dwindling supply and rising demand,[100] human rights abuse and other socially damaging action by non-democratic national governments enriched by fossil fuel resources (primarily oil),[101] questions regarding the stability and sustainability of agricultural production methods,[102] water contamination and overuse affecting human populations and natural systems

97. Felder, *supra* note 9, at 95–96.

98. *See, e.g.*, Andreas Goldthau & Benjamin K. Sovacool, *The Uniqueness of the Energy Security, Justice, and Governance Problem*, 41 ENERGY POL'Y 232, 238 (2012) (arguing that energy transitions are "susceptible to transform the cultural and social fundamentals of entire nations").

99. Even with the UNFCCC controls in place at the time, the U.S. National Research Council estimated $62 billion in *non-climate* damages from coal in 2005, which equates to $66/ton. Lyster, *supra* note 79, at 16. Damages are significantly higher (proportionally) in developing countries where pollution controls are significantly weaker or non-existent. *See* INT'L ENERGY AGENCY, *supra* note 90, at 319–20 (discussing health problems caused by air pollution, and comparing air pollution levels of OECD and non-OECD countries).

100. Global energy demand is expected to increase by over one-third by 2035, with much of the increase attributable to non-OECD countries (such as China, India, and the Middle East). *See* IEA FACTSHEET, *supra* note 3, at 1. Additionally, an investment of $37 trillion in our energy supply system would be necessary to meet increasing energy demands. *Id.*

101. Journalist and commentator Tom Friedman refers to the anti-democratic influence of oil economics in Middle Eastern countries as "the First Law of Petropolitics." THOMAS L. FRIEDMAN, HOT, FLAT, AND CROWDED: WHY WE NEED A GREEN REVOLUTION—AND HOW IT CAN RENEW AMERICA 112–13 (2008) ("As the price of oil goes up, the pace of freedom goes down; and as the price of oil goes down, the pace of freedom goes up."); *see also* Goldthau & Sovacool, *supra* note 98, at 233 ("The world's known oil reserves are concentrated in a handful of largely volatile countries . . . whose governments have been known to yield to the temptation to use their control of this vital resource for political ends.").

102. *E.g.*, Jeremy Woods et al., *Energy and the Food System*, 365 PHIL. TRANSACTIONS ROYAL SOC'Y BIOLOGICAL SCI. 2991, 3003–05 (2010) (highlighting the potential negative impacts of energy prices on agricultural outputs in discussing the relationship of fossil fuel markets, climate change, and agricultural processes).

already suffering from inadequate water supply,[103] and the energy poverty associated with the 1.6 billion people who lack even basic access to electricity.[104] These issue linkages highlight that energy policy does not operate in a vacuum in which only the carbon emissions are important. Existing energy policy has major negative externalities throughout the globe. At a minimum, they must be considered in energy policy reform. The potential to improve local, national, or regional conditions as part of an energy reform effort may also provide helpful political and economic incentives for efforts to reduce or replace fossil fuel dependence in a given geographic area or economic and policy sector.

3. Energy and Geopolitical Power

While social and environmental externalities of the energy status quo might provide leverage for reform, the potential for energy reform to implicate for states' core security and power concerns may prove to be one of the toughest challenges facing efforts to restructure global energy policy.[105] As one scholar describes it, "energy governance represents a contested domain between power-based geopolitical concerns and multilateral and cooperative governance."[106] Geopolitical policy analyst and scholar Joseph Nye describes oil as "the most important raw material in the world"[107] and highlights the complex set of forces from which the existing geopolitical situation emerged, including the independence of former colonies, the Iranian Revolution, an inadvertent transfer of technology from

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103. *See, e.g.*, IEA FACTSHEET, *supra* note 3, at 6 (predicting that energy use in the future will see a rise in water consumption by eighty-five percent); PARRY ET AL., *supra* note 43, at 11–16 (discussing the implications climate change will have on freshwater resources, how they are managed, and how various parts of the world will be affected).

104. LESAGE ET AL., *supra* note 41, at 2.

105. Kirsten Westphal, *Energy Policy Between Multilateral Governance and Geopolitics: Whither Europe?*, INTERNATIONALE POLITIK & GESELLSCHAFT, no. 4, 2006 at 44, 52 (stating that energy security and the energy sector as a whole remain vital for both a country's national economy and security).

106. Benjamin K. Sovacool & Ann Florini, *Examining the Complications of Global Energy Governance*, 30 J. ENERGY & NAT. RESOURCES L. 235, 256 (2012) (citing Westphal, *supra* note 105, at 45).

107. JOSEPH S. NYE, JR., THE FUTURE OF POWER 64 (2011).

multinational corporations to oil-rich developing countries,[108] and an implicit security-for-oil relationship between the world's most oil-rich nation and the world's strongest military power.[109] Thus, "oil is the exception, not the rule" when it comes to the role of natural resources in global power relationships because control of oil and its distribution have literally shaped key global power relationships, rather than being determined by pre-existing political power relationships.[110] Reducing oil's dominance, therefore, would have massive geopolitical implications—and potentially impose massive economic losses on particular countries—with global power ramifications far beyond anything yet precipitated by existing environmental law.

4. International Energy Governance Challenges

The existing global energy governance structure is highly decentralized and, at least arguably, incoherent.[111] Unlike environmental law, which is crowded with highly institutionalized regimes confronting an array of global environmental challenges,[112] there is arguably no global energy governance institution with the capacity to exercise global

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108. The technology transfer referred to is of the type that Driesen and Popp describe as "meaningful technology transfer," in that it involved enhancing the capacity and know-how of local economies within the countries where multinational corporations operated. *See* David M. Driesen & David Popp, *Meaningful Technology Transfer for Climate Disruption*, 64 J. INT'L AFF. 1, 5–8 (2010) (defining technology transfers and meaningful technology transfers). The effect of this particular transfer was to shift political control of oil in a way that was unrelated to GHG mitigation goals, but it may be that a similar transfer of clean energy technology is required to realize climate change mitigation goals. *See* NYE, *supra* note 107, at 65–66 (describing the inadvertent technology transfer that occurred in oil-rich developing countries).

109. NYE, *supra* note 107, at 64–70. As Nye describes it, a system that was once ruled by the "seven sisters"—an oligarchy of seven large transnational corporations—is now governed by a delicate political balance centering on Saudi Arabia, the United States, and several lesser players. *Id.* at 64–66.

110. *Id.* at 64.

111. Sovacool & Florini, *supra* note 106, at 252 (positing that energy governance "incoherence is . . . amplified at the international level, where authority is fragmented and often altogether lacking").

112. *See, e.g.*, Davies, *supra* note 4, at 484, 486–90 (examining the present state of environmental law and the variety of challenges environmental law regimes address).

leadership authority on any subset of energy issues.[113] Instead, there is an unwieldy assortment of institutions (one recent *non-exhaustive* survey compiled fifty institutions that serve as "global energy governors") with a wide array of mandates, geographic authority, and policy competencies.[114] Thus, although global energy policy reaches the heart of many of the core challenges of the twenty-first century—security, development, and the environment—governance of the system has evolved primarily into a set of decentralized, mostly unconnected, and primarily political (as opposed to legal) institutions with limited impact.[115] There are, in other words, no clear lines of authority in energy governance and no significant indications that an effective sector-wide governance system will develop.

Some observers suggest that the governance institution that may offer the brightest hope for actually improving global energy policy is the International Renewable Energy Agency (IRENA), an institution with no binding authority and relatively small financial capacity that seeks primarily to promote renewable energy development through information-based strategies and capacity building in least developed

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113. *See* LESAGE ET AL., *supra* note 41, at 72 ("As regards leadership in global energy governance, the world's cockpit is still more or less empty."); Sovacool & Florini, *supra* note 106, at 252 (discussing the incoherence and fragmentation of global energy governors and describing our current governance model as "full of sound and fury, yet . . . far too little substance").

114. Sovacool & Florini, *supra* note 106, at 239 tbl.2 (providing a table summarizing fifty "global energy governors"); *see also* Timothy Meyer, *The Architecture of International Energy Governance*, 106 AM. SOC'Y INT'L L. PROC. 389, 390 (2012) ("An alphabet soup of international agreements and organizations deals in some way or another with international energy . . . ."). One can divide some of the major institutions in energy governance into producer versus consumer clubs, or into economic institutions and environmental institutions (primarily the UNFCCC), depending on how one looks at the field. *Id.* at 391.

115. *See, e.g.*, Carlarne, *supra* note 14, at 57 (concluding that "the conventional framework is failing"); Sovacool & Florini, *supra* note 106, at 252 (emphasizing the disconnect between global energy governance institutions). For example, a recent in-depth study of global energy governance explored whether the G8's apparent assumption of leadership in energy governance is a sign that centralized energy governance is developing, but concluded that it fails to provide a viable model for improving global energy governance. *E.g.*, LESAGE ET AL., *supra* note 41, at 172–73 (concluding that the "G8 has performed below expectations" and has displayed "serious shortcomings").

countries.[116] At a time when multilateral environmental regime-building efforts have slowed considerably, the creation and rapidly growing membership of IRENA stands out.[117] While it may signal a desire by some nations to counteract a perceived fossil fuel bias in the IEA—the primary pre-existing international energy institution—IRENA's relative success in advancing its renewables-promotion mission also suggests the potential of non-legalistic (i.e., "soft" or non-binding) approaches to international environmental governance to influence behavior.[118] Unlike the UNFCCC regime, IRENA's efforts to promote renewable energy are intentionally *not* framed in terms of climate change or environmental benefit, even though such concerns motivate much of the growth in renewable energy technology that IRENA promotes.[119] Thus, perhaps IRENA illuminates the potential for making progress on energy and climate challenges through adopting new approaches, and perhaps the value of its story relates to the need for rethinking existing perspectives on international climate change and energy policy.

II. COMPLEXITY AND THE EMERGENCE OF CLIMATE CHANGE

The various features of energy policy briefly described above suggest the complex context of social, ecological, and technological interactions that efforts to catalyze energy sector changes must navigate if they are to produce climate change mitigation.[120] In this policy environment, identifying interventions that will produce large-scale beneficial changes

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116. *See* Johannes Urpelainen & Thijs Van de Graaf, *The International Renewable Energy Agency: A Success Story in Institutional Innovation?*, INT'L ENVTL. AGREEMENTS: POL., L. & ECON., Sept. 2013, *available at* http://link.springer.com/article/10.1007%2Fs10784-013-9226-1.

117. IRENA was created months before the UNFCCC negotiations in Copenhagen signaled the apparent end of hope for a new binding climate agreement. In the next four years, over 100 countries ratified the agreement creating this new, stand-alone institution. Thijs Van de Graaf, *Fragmentation in Global Energy Governance: Explaining the Creation of IRENA*, 13 GLOBAL ENVTL. POL. 14, 14 (2013).

118. Urpelainen & Van de Graaf, *supra* note 116, at *10.

119. *Id.*

120. *Cf.* Handke & Hey, *supra* note 9, at 2 ("[C]limate measures must dovetail with energy policy and regulation of the energy sector if they are to have any effect.").

requires strategies very different from the top-down UNFCCC process, a point illustrated by IRENA's relatively successful start.[121] Complex systems theory (or "complexity theory") offers one way in which we might begin to understand the mitigation challenge differently and develop more effective policy interventions.

In 1997, coincidentally the same year that the Kyoto Protocol was signed, J.B. Ruhl warned that "[u]nless environmental law sheds its traditional premises and methods, the findings of complexity theory suggest we will not achieve the kind of environmental law system needed to confront our changing future."[122] The recently developed concepts of the "anthropocene" and an Earth system in a "no analogue state" express an exceptional degree of human impact on the planet's environmental systems[123] that gives definition to the "changing future" referenced in Ruhl's 1997 warning.[124] Facing these

121. *See* Urpelainen & Van de Graaf, *supra* note 116, at *12.

122. Ruhl, *Thinking*, *supra* note 9, at 941.

123. A number of scientists and others have come to highlight the unprecedented nature of human impacts on the earth's environmental systems by describing the current era of time as the "Anthropocene." Atmospheric chemist Paul Crutzen (a Nobel laureate) and ecologist Eugene Stoermer coined the term in 2000. *See* Paul J. Crutzen & Eugene F. Stoermer, *The "Anthropocene"*, GLOBAL CHANGE NEWSL. (Int'l Geosphere-Biosphere Programme, Stockholm, Swed.), May 2000, at 17, 17–18, *available at* http://www.igbp.net/download/18.316f18321323470177580001401/1316517410973/NL41.pdf. The globally-recognized organization that describes geological periods is The International Union of Geological Sciences (IUGS). Although we are still officially in the Holocene, according to IUGS, the organization has begun a working group to consider the concept of the Anthropocene. Subcommission on Quaternary Stratigraphy, *Working Group on the 'Anthropocene'*, INT'L COMMISSION ON STRATIGRAPHY, http://quaternary.stratigraphy.org/workinggroups/anthropocene/ (last updated Aug. 1, 2013). The concept of a "no analogue" state expresses the idea that environmental systems have been so intensely impacted by human-caused forces that past empirical records are not reliably helpful to predicting outcomes. *E.g.*, Arild Underdal, *Complexity and Challenges of Long-Term Environmental Governance*, 20 GLOBAL ENVTL. CHANGE 386, 388 (2010). The "no analogue" concept has particular relevance in ecology and species conservation. *E.g.*, Diana Stralberg et al., *Re-shuffling of Species with Climate Disruption: A No-Analog Future for California Birds?*, PLOS ONE, Sept. 2009, at 1, 5, *available at* http://www.plosone.org/article/fetchObject.action;jsessionid=E47834D0CCB2481E2BD368CCBCAAE227?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0006825&representation=PDF ("The likely emergence of novel, no-analog communities over the coming decades presents enormous conservation and management challenges.").

124. *See* Ruhl, *Thinking*, *supra* note 9, at 941.

complex problems requires evolution in the approaches of law and governance.[125]

Indeed, the Kyoto Protocol and its failure to catalyze effective climate governance now seem to support Ruhl's conclusion.[126] The emphasis on a legalistic and top-down treaty structure to address climate change—the overarching goal of UNFCCC negotiations for nearly twenty years and expressed most clearly in the Kyoto Protocol and its quantifiable emissions reduction commitments[127]—reflected on the international level the core problem with domestic environmental law that led Ruhl to call for "a truly radical transformation of environmental law."[128] The core argument expressed by Ruhl and an increasing number of other environmental law scholars is that most of environmental law reflects a "reductionist, linear, predictivist mentality" and associated governance approach that fits poorly with the complex environmental systems that they regulate.[129] Building

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125. *E.g.*, Craig Anthony (Tony) Arnold, *Fourth-Generation Environmental Law: Integrationist and Multimodal*, 35 WM. & MARY ENVTL. L. & POL'Y REV. 771, 798 (2011) (suggesting that the complexity of environmental problems led to evolutionary changes in U.S. environmental regulation).

126. *See* Boyd, *supra* note 14, at 548–50 (discussing the Kyoto Protocol's top-down, global approach, its failure to implement effective climate governance, and the need for a complex system to address climate change).

127. *See id.* at 548 (explaining that "the conviction that there can and should be a blueprint for comprehensive climate governance, manifest most prominently in the Kyoto architecture and in the efforts to negotiate a successor treaty" led to many of the disappointments and failures of the climate regime).

128. Ruhl, *Thinking*, *supra* note 9, at 941–42. Although most of his analysis focuses on domestic environmental law, Ruhl suggests that the transformation of environmental law should embrace an overall goal of *global* sustainable development, with decision-making processes based upon adaptive management principles, and the use of biodiversity preservation as a performance metric. *Id.* at 942. It is impossible to know what the international climate change regime would look like today if it had embraced Ruhl's suggestions, of course, but the focus on a top-down treaty with quantifiable emissions reductions as the primary goal seems about as contrary to those suggestions as anything in U.S. domestic environmental law.

129. *Id.* at 940 (characterizing environmental law as "mired in a reductionist, linear, predictivist mentality"); *see also* Robin Kundis Craig, *Learning to Think About Complex Environmental Systems in Environmental and Natural Resource Law and Legal Scholarship: A Twenty-Year Retrospective*, 24 FORDHAM ENVTL. L. REV. 87, 101–02 (2013) ("While scholars may accept the new realities of complexity theory, much of environmental and natural resources law remain based in paradigms of complicatedness,

on that critique of environmental law, Parts III and IV of this Article suggest that mitigation efforts may be improved by applying a similar analysis to the overlapping social, ecological, and technical systems affecting global energy policy, which can be accurately conceptualized as a single large complex system ("the global energy system") that is the core subject of climate change mitigation regulation.

Complex systems theory offers a perspective and a mode of analysis that is radically different than many of the assumptions underlying the law generally and environmental law in particular. The most familiar manifestation of this arises in debate over the need for flexibility in the face of uncertainty, contrasted with the value of certainty and finality in legal rules and legally significant decisions.[130] A further exposition of complexity theory concepts may elucidate the value of rethinking pre-existing legal approaches to complex issues such as climate change.

Complexity theory originated in the physical sciences in the early to middle twentieth century and, with some modification, became particularly important in ecological science by the 1990s.[131] By the dawn of the twenty-first century, the concept of "socio-ecological systems" (SESs) had developed as a useful way of understanding the interactions of human social systems with natural environmental systems. The majority of literature on SESs examines relatively small scales, such as forest or wetland ecosystems.[132] However, there

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predictability, and stationarity—always a bad fit to ecological reality, and an increasingly problematic mismatch in a climate change era.").

130. One interesting example highlighting the challenges of this tension was the attempt to transform forest management under the George W. Bush administration, which adopted the language of adaptive management—long called for by environmentalists—in an attempt to remove the firm regulatory requirements that limit logging in national forests. Andrew Long, *Auditing for Sustainable Forest Management: The Role of Science*, 31 COLUM. J. ENVTL. L. 1, 5 (2006).

131. *See* Ruhl, *Complexity Theory*, *supra* note 9, at 857 n.9.

132. *See, e.g.*, Ruhl, *Thinking*, *supra* note 9, at 948–49 (using the example of a single tree as a complex-adaptive system); *cf.* Ahjond S. Garmestani et al., *Panarchy, Adaptive Management and Governance: Policy Options for Building Resilience*, 87 NEB. L. REV. 1036, 1041 (2009) ("Scale is the critical variable in monitoring and therefore policy associated with linked socio-ecological systems. Cumulative impacts have the capacity to 'scale up' in terms of their effect. As an illustration, large scale destruction and degradation of wetlands, and the ecological services associated with those wetlands, has occurred primarily as a result of innumerable, small conversions of wetlands for

is also a growing body of work that examines the relevance of the SES perspective for global-scale change.[133] In 2002, Lance Gunderson and C.S. Holling published an edited volume articulating a theory of "panarchy" as an "integrative theory to help us understand the changes occurring globally," which are "economic, ecological, social, and evolutionary."[134] Panarchy theory illustrates, among other things, the multiscale and overlapping nature of SESs.[135]

Beginning with Ruhl's work in the 1990s, a number of environmental law scholars have explored how complexity-based theories may be valuable to environmental law, although significant analytical work remains to clarify its implications for governance, and few of these theoretical explorations have been tested through policy implementation, especially at large scales.[136] Indeed, scholars who have written extensively on the importance of incorporating the insights of complexity theories note explicitly that it is a difficult task for which we have very limited guidance.[137] Yet complexity theory can provide an

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agricultural and urban development—a tyranny of many small decisions." (footnote omitted)).

133. *See, e.g.*, Boyd, *supra* note 14, at 478–79 (discussing the use of these models to simulate "the oceans, the cryosphere, the biosphere, and human activities").

134. C.S. Holling, Lance H. Gunderson & Donald Ludwig, *In Quest of a Theory of Adaptive Change*, *in* PANARCHY: UNDERSTANDING TRANSFORMATIONS IN HUMAN AND NATURAL SYSTEMS 3, 5 (Lance H. Gunderson & C.S. Holling eds., 2002).

135. Garmestani et al., *supra* note 132, at 1037 ("Unlike the top-down control envisioned in traditional hierarchies, connectivity between adaptive cycles in a panarchy can be from levels above or below. In a hierarchy, lower-level patterns and processes are dominated by higher levels in the hierarchy. Panarchy differs from this characterization of nesting, with respect to complex systems, in that conditions can arise that trigger 'bottom-up' (i.e., cross-scale cascading) change in the system. This model of socio-ecological systems more accurately captures the 'surprise' or uncertainty inherent in such systems. Further, levels in a panarchy are not static states, but rather adaptive cycles that are interconnected to other adaptive cycles in the panarchy.").

136. Andreas Duit et al., *Governance, Complexity, and Resilience*, 20 GLOBAL ENVTL. CHANGE 363, 365–67 (2010); *see also* Craig, *supra* note 129, at 102 ("Complexity theory and resilience thinking offer the brightest hope for the future of environmental and natural resources law and policy in this climate change era, and so we should all hope that they continue to inspire transformative scholarship.").

137. *E.g.*, J.B. Ruhl, *Panarchy and the Law*, ECOLOGY & SOC'Y, Sept. 2012, at 2, 4, *available at* http://www.ecologyandsociety.org/vol17/iss3/art31/ES-2012-5109.pdf (observing that "translating and operationalizing panarchy

alternative way of examining large social systems and their interaction with natural systems in order to yield policy insights that better account for the uncertainty often found in environmental challenges, as well as the uncertainties of the political and social systems within which law is created to address these challenges.[138]

Complex systems are not merely "complicated" systems, which involve many independent variables.[139] Complex systems are systems in which the components exhibit dependencies such that the system as a whole has properties that "emerge" and cannot be explained as the sum of the constituent parts.[140] Further, these systems demonstrate nonlinearity, meaning that they cannot be predicted with proportional mathematics.[141] In applications that are most relevant to environmental law, a key feature of nonlinearity is its unpredictability, which is related to complex systems' self-organizing characteristics and the potential for small perturbations in the system to produce large and even transformational changes.[142] This latter potential reflects the extreme sensitivity of complex systems in their current or starting states, as well as path dependency dynamics.[143] It also

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theory into law will be a very difficult undertaking," but nonetheless warning that lawyers should "not underestimate the need to make that move").

138. Daniel A. Farber, *Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty*, 37 U.C. DAVIS L. REV. 145, 172–73 (2003); Ruhl, *supra* note 131, at 892–93, 905, 913. For a creative and well-developed example of using complexity theory concepts to reimagine a complex environmental issue area, see Jim Chen, *Webs of Life: Biodiversity Conservation as a Species of Information Policy*, 89 IOWA L. REV. 495, 502 (2004) (taking the unique approach of describing environmental law as an "information platform").

139. Craig, *supra* note 129, at 88 ("Complexity scientists generally distinguish *complex* systems from *complicated* systems.").

140. *See* JOHN H. HOLLAND, EMERGENCE: FROM CHAOS TO ORDER 121–22 (1998) (discussing the limitations of only looking at the "average" behavior of each part of a complex system); *see also* Craig, *supra* note 129, at 88–91 (listing several distinguishing properties of complex systems).

141. Ruhl, *supra* note 131, at 854 ("[T]he interaction of law and society can be modeled using the characteristics of dissipative, nonlinear dynamical systems; that is, when conceived as a unified system, the interaction of law and society evolves in an unfolding nonreversible manner that is not based on components with directly proportional relationships capable of being graphed as a straight line." (footnote omitted)).

142. *See id.* at 875–80 (discussing chaos and its impact on complexity theory).

143. *Id.*

reflects the impossibility of fully calculating the effects of an intervention affecting even small components of any system in which the components are interdependent. Any change to one component will cause changes to the others, which then cause a new set of changes to occur, and so on in a dynamic and continual process that constitutes the trajectory of the system.[144] In relatively rare instances, very minor (even immeasurable) changes to a small component can produce extremely large consequences for the system as a whole,[145] but more often, systemic change is a process of accretion and reaction over time and may be understandable, but not fully predictable.[146]

Key concepts related to change in complex systems are frequently discussed in terms of "resilience," "adaptability," and "transformation."[147] The use of these terms is not consistent throughout all types of complex systems literature, nor is it entirely consistent within subsets of the literature.[148] Nonetheless, each of the terms has meaning across systems contexts. In the "resilience thinking" literature, which is among the strands of complexity theory that has exerted the most influence on recent environmental law scholarship,[149] "resilience" is defined as the capacity of a socio-ecological system to change yet remain within the thresholds that define

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144. *See* David G. Post & David R. Johnson, *"Chaos Prevailing on Every Continent": Towards a New Theory of Decentralized Decision-Making in Complex Systems*, 73 CHI.-KENT L. REV. 1055, 1060–73 (1998) (providing an exceptionally clear discussion of this concept by use of a garden metaphor).

145. This extreme situation is an example of "power laws," which are not common even in systems, but provide a very clear illustration of how different systems operations can be from traditional probability and common expectations of cause and effect. Farber, *supra* note 138, at 153–54.

146. *Id.* at 153.

147. *Cf.* Carl Folke et al., *Resilience Thinking: Integrating Resilience, Adaptability and Transformability*, ECOLOGY & SOC'Y, Dec. 2010, at 20, 20, *available at* http://www.ecologyandsociety.org/vol15/iss4/art20/ES-2010-3610.pdf (describing resilience, adaptability, and transformability as three central aspects of complex systems). Folke et al. use the term "transformability" to express an element of the concept discussed here and elsewhere as "transformation." *Id.*

148. *See id.* at 20, 22 (noting "confusion" that results from publications using these terms in multiple ways; additionally, the author provides a glossary to clarify the definition of key terms).

149. *See* Robin K. Craig & Melinda H. Benson, *Replacing Sustainability*, 46 AKRON L. REV. 841, 868 (2013).

its trajectory.[150] Although several possible "system states" may exist inside the thresholds within which a resilient system tends to remain, systems are resilient when they respond to external or internal forces through change (perhaps even to other system states within the thresholds) without being pushed into a fundamentally different trajectory or fundamentally new system.[151] "Adaptability" is the system's ability to respond to such forces—its ability to change—which underlies its resilience because such responsive changes allow the system to avoid being fundamentally altered by the forces affecting it.[152] On the other hand, "transformation" refers to a fundamental reorganization of a system into a new system with a different trajectory.[153] This occurs when forces exceed the adaptive capacity of the system and thus overwhelm its ability to maintain resilience.[154]

Other formulations of the transformation concept are also important to note, however, and generally refer to less radical changes. Thus, transformation can be understood as a change in the system state (without necessarily exceeding fundamental limits), as exemplified by changing a pasture managed for raising sheep to one that is managed for goats.[155] The concept of "resilience" warrants some additional attention because not only has it been used to express different concepts, but also because at least two different types of resilience have been

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150. Folke et al., *supra* note 147, at 21; *see* C.S. Holling, *Resilience and Stability of Ecological Systems*, 4 ANN. REV. ECOLOGY & SYSTEMATICS 1 (1973) (introducing the concept of resilience).

151. *See* Craig & Benson, *supra* note 149, at 863 (describing system states in the context of resilience theory). One relevant application of this concept at a global scale is the idea that variations between ice and non-ice ages within the Holocene represent changes in the system state of the planet, but not a fundamental transformation, and that the Anthropocene concept expresses the potential for fundamental transformation of these systems. *See* Will Steffen et al., *The Anthropocene: From Global Change to Planetary Stewardship*, 40 AMBIO 739, 755–56 (2011).

152. Folke et al., *supra* note 147, at 21 ("Adaptability captures the capacity of a SES to learn, combine experience and knowledge, adjust its responses to changing external drivers and internal processes, and continue developing within the current stability domain or basin of attraction." (citation omitted)).

153. *Id.* at 22–23.

154. *See id.*

155. Brian Walker et al., *A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems*, ECOLOGY & SOC'Y, June 2006, at 13, 21, *available at* http://www.ecologyandsociety.org/vol11/iss1/art13/.

widely recognized. The definition suggested above reflects "ecological resilience," which refers to "resistance" or the ability to absorb disturbance without fundamental alteration of the system.[156] The concept of "engineering resilience," however, is distinct and refers to the ability to "recover" or return to a "steady state" of equilibrium.[157]

Complex systems theory focuses on the interactions among components of a system, whether the system is ecological, social, or another type (including socio-ecological and socio-technical).[158] The theory tends to highlight the potential for relatively small-scale adjustments to a component or an interaction of components to create a ripple effect that can ultimately lead to large-scale changes of the system as a whole.[159] This reflects the overlapping and nested nature of many systems.[160] For example, smaller scale systems may undergo transformation in ways that serve to enhance the adaptability and resilience of larger-scale systems in response to significant forces driving change.[161] The state of the system at one point in time generally defines the potential pathways through which changes may take effect and reverberate, although these can be very difficult or impossible to identify, let alone predict, because of the extremely high number of potential interactions and configurations within complex systems.[162] In this way, complex systems theory accounts for the uncertainty and unpredictability of complex systems and offers an explanation, although not one that offers concrete and

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156. J.B. Ruhl, *General Design Principles for Resilience and Adaptive Capacity in Legal Systems: With Applications to Climate Change Adaptation*, 89 N.C. L. REV. 1373, 1376–77 (2011) (discussing the differences between ecological and engineering resilience concepts).

157. *Id.* at 1377 (describing the effect on the movement of a ball at the bottom of a tall, narrow vase (a metaphor for engineering resilience) compared to the effect on the movement of a ball in a wide but shallower bowl (a metaphor for ecological resilience) to illustrate the difference between the types of resilience).

158. *See* C.S. Holling, *Understanding the Complexity of Economic, Ecological, and Social Systems*, 4 ECOSYSTEMS 390, 390 (2001).

159. *See* Folke et al., *supra* note 147, at 20–21.

160. *See id.*

161. *See id.* at 24.

162. *See, e.g.*, Craig, *supra* note 129, at 92 ("One of the important lessons for environmental and natural resources law from complexity science is that uncertainty and unpredictability are inherent limitations on the legal system's ability to perfectly control and regulate its subjects . . . .").

specific predictions, of how and why alterations to the components of a system can produce change effects ranging from nearly imperceptible to transformation of the system as a whole.[163] Although this type of nonlinear process is not fully predictable, it may create opportunities to adjust components of a system in order to initiate a sequence of interactions that produce large-scale changes in trajectory, even where direct system-wide change would be practically impossible. When complexity analysis is applied to socio-ecological systems, it generally results in policy insights that are very different from the traditional (linear and reductionist, in most cases) approach to an issue.[164] Climate change mitigation is no different from many other issues in this respect.

III. RECONCEPTUALIZING THE MITIGATION CHALLENGE AS A COMPLEX SYSTEMS PROBLEM

Over the last fifteen to twenty years, environmental scholars began to recognize the value of complex systems theory for environmental policy analysis and design.[165] Somewhat ironically, this approach has gained the most traction in the context of climate change adaptation, but has received almost no attention in the context of climate change mitigation governance.[166] Yet, the high level of global GHG emissions, particularly since the middle of the twentieth century, can easily be understood as an emergent property of a

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163. *See id.* at 88–89, 102 (defining complex systems and advocating the use of complexity theory). *See generally* Farber, *supra* note 138, at 172–73 (arguing that power laws—where the possibility of a freak outcome weighs heavily in the analysis—apply to environmental issues, and that complexity theory can help explain such freak outcomes and suggest possible ways to handle them).

164. Among the first articles to make this point in legal scholarship was Ruhl, *Complexity Theory*, *supra* note 9; *see also* Craig, *supra* note 129, at 91–93 (proposing the application of complexity science to transform environmental law to a dynamic governance system capable of adapting to change and uncertainty with reference to socio-ecological systems).

165. *See* Craig, *supra* note 129, at 100–01 ("Are we to the point where the complexity of ecosystems and socio-ecological systems is accepted as a given by environmental and natural resources law scholars? Probably.").

166. *Cf.* Outka, *supra* note 4, at 1684–86 (discussing the complexity of the legal system and climate change as barriers to effective climate change regulation).

global energy system.[167] This Part begins to explore whether examining the mitigation challenge as a complex systems problem, by conceiving of fossil energy dominance and related GHG emissions as undesirable emergent properties of a complex "global energy system," can provide useful policy insights.

If energy policy can accurately be understood as a complex global energy system, policy analysis may be made more fruitful by accounting for the complex systems properties it possesses.[168] Attention to the dynamic and nonlinear processes of complex systems, sensitivity to system state and path dependency, and the potential for relatively small alterations to provoke the emergence of major systemic state changes at a very large scale provide ways of thinking about the global energy system that are likely to yield policy recommendations very different from the incremental and legalistic efforts that have characterized most of environmental law, in the United States and internationally, and which have repeatedly failed to produce significant climate change mitigation.[169]

It would be hard to imagine a global system that is less likely than the global energy system to respond to the types of reductionist processes and methods that have come to characterize nearly all of environmental law at both domestic and international levels.[170] Thus, if global energy governance holds out hope for climate change mitigation—and with the

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167. *See, e.g.*, Felder, *supra* note 9, at 89 (describing the global energy system as "a complex, large-scale, integrated, open, and socio-technical (CLIOS) system"); *see also* JOSEPH M. SUSSMAN, THE "CLIOS PROCESS:" A USER'S GUIDE (2007), *available at* http://ocw.mit.edu/courses/engineering-systems-division/esd-04j-frameworks-and-models-in-engineering-systems-engineering-system-design-spring-2007/readings/clios_process.pdf (discussing the CLIOS systems, which is a concept that grows from engineering literature).

168. *See* Felder, *supra* note 9, at 105.

169. *See id.* at 104–05.

170. *Id.* at 93 ("Coincident with the needs of policymakers to reevaluate global climate change mitigation policy, the importance of a multi-disciplinary approach to solving intractable social problems has long been recognized. These problems consist of intertwined technological and social complexities that cannot be adequately addressed by a reductionist scientific approach." (footnote omitted)); *see* Goldthau & Sovacool, *supra* note 98, at 232 ("As we shall argue in this article, energy is, among all policy fields exhibiting externalities of a global scale, by far the most complex, path dependent, and embedded one."); *see also* Sovacool & Florini, *supra* note 106, at 252–56 (discussing the challenges of energy governance).

near collapse of UNFCCC process focused primarily on traditional environmental law approaches, it may be the only hope—proposals need to account for the extremely messy governance structure and the multiple layers of social and economic issues that characterize energy policy.[171] More importantly, to be effective, such proposals should account for the interaction of the diverse and diffuse components of energy policy. It is the interactions of these components that are most relevant to demonstrate the existence of a complex global energy system because it is through this interaction that the system produces emergent properties.[172] Chief among the emergent properties is the dominance of fossil-fuel-based technologies.[173] The longstanding dominance of these technologies is an example of what technology literature often describes as technological "lock-in," but which will be more familiar to environmental law scholars as a form of resilience.[174] One way of thinking about climate change, then,

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171. *See, e.g.*, Carlarne, *supra* note 14, at 3 (emphasizing the need to move on from our current global climate governance system and pursue "a web of multi-level, multi-scale systems" to accommodate the complex economic, social, and political issues presented by climate change); Sovacool & Florini, *supra* note 106, at 260–63 (discussing potentially promising approaches to reforming global energy governance).

172. *See, e.g.*, Sovacool & Florini, *supra* note 106, at 252 (listing examples of the "disparate topics" that global energy regulators are tasked with addressing); *see also* Donald T. Hornstein, *Complexity Theory, Adaptation, and Administrative Law*, 54 DUKE L.J. 913, 920 (2005) ("When mechanisms of self-assembly lead to properties of a system that are not shared by its constituent parts, these properties are called emergent.").

173. *See* Davies, *supra* note 4, at 481 ("Energy regulation in the United States clearly 'favors large-scale, high-technology, capital-intensive, integrated, and centralized producers of energy from fossil fuels.'" (quoting Joseph P. Tomain, *The Dominant Model of United States Energy Policy*, 61 U. COLO. L. REV. 355, 375 (1990))); *see also* IEA FACTSHEET, *supra* note 3, at 1 (stating that fossil fuels accounted for 81% of the global energy supply in 2012).

174. *See* Duit et al., *supra* note 136, at 365–67 (applying the concept of resilience to governance issues). *See generally* Sovacool, *supra* note 76, at 4504–12 (examining the economic, political, and behavioral impediments of implementing renewable energy systems which in turn support the continued dominance of fossil fuels). One may fairly question whether the resilience of the global energy system in a state of fossil fuel dominance is ecological resilience or engineering resilience. Arguably, events such as the 1970s oil crisis suggest that the system tends to "bounce back" rather than absorb shocks and, thus, can be understood as exhibiting engineering resilience rather than ecological resilience. *See supra* notes 156–57 and accompanying text.

is to view fossil fuel dominance as a particularly important emergent property of the global energy system, one which has become so dominant that it threatens the stability of other systems interacting with the energy system—most notably, the climate system.

A. THE GLOBAL ENERGY SYSTEM AS A COMPLEX SYSTEM

In his 1997 article calling for a transformation of environmental law, J.B. Ruhl encouraged creation of an environmental law system that enables "complex adaptive system forces to take hold and flourish,"[175] a theme which has been echoed with increasing frequency in recent years. Of course, basing a regulatory strategy on complex-systems forces presupposes that one is working with a complex system. So, how does one determine whether a large-scale system such as the global energy system is indeed a complex system? In assessing the objects of environmental regulation, Ruhl identifies the following general properties of complex adaptive systems: aggregation, nonlinearity, flows, diversity, and self-criticality.[176] In discussing complexity theory as a descriptive tool for administrative law, Donald Hornstein identifies emergence from self-assembly, sensitivity to initial conditions, and nonlinearity as indicative of a complex system.[177] In a recent article analyzing international environmental law as a complex adaptive system, the authors point to related processes of nonlinearity, emergence, and self-organization.[178] One could also examine the literature from other disciplines, particularly literature which explores differences between natural and human systems in terms of complexity and adaptive

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175. Ruhl, *Thinking*, *supra* note 9, at 942; *see also id.* at 941–42 (suggesting that the transformation should embrace an overall goal of *global* sustainable development, with decision-making processes based upon adaptive management principles, and the use of biodiversity preservation as a performance metric).

176. *Id.* at 943–53. *See generally* J.B. Ruhl & Harold J. Ruhl, Jr., *The Arrow of the Law in Modern Administrative States: Using Complexity Theory to Reveal the Diminishing Returns and Increasing Risks the Burgeoning of Law Poses to Society*, 30 U.C. DAVIS L. REV. 405 (1997) (discussing similar properties of complex adaptive systems).

177. Hornstein, *supra* note 172, at 913, 916.

178. Rakhyun E. Kim & Brendan Mackey, *International Environmental Law as a Complex Adaptive System*, 14 INT'L ENVTL. AGREEMENTS 5, 7–8 (2014).

characteristics,[179] which may have value in future efforts to define precise reform actions aimed at mitigating climate change through the global energy system. It is also important to recognize that complexity theory includes concepts related to the "attractors" of systems.[180] Attractors can be "strange" and complex, but can also be more stable, fixed or cyclical, and some mix of these attractors is at play in most systems, leading to their adaptability on what has been called the "edge of chaos."[181] For present purposes, however, a general recognition of complex systems properties is sufficient to illustrate that the global energy system acts as a complex system. Thus, I suggest that the global energy system can be understood as a complex system through two clusters of related characteristics: (1) self-organization and emergence, reflecting what Ruhl describes as "aggregation;"[182] and (2) nonlinearity through flows based on a sensitivity to initial conditions, reflecting both the concept of path dependency and the potential for small changes to effect large systemic effects that may, on relatively rare occasions, even lead to fundamental transformation of the system (such transformation is often referred to as "catastrophe").[183] Moreover, the multiscalar and overlapping legal, sectoral, and physical systems composing the global energy system illustrate that it has characteristics of a panarchy.[184] Many of these features are illustrated in the discussion above, but are made somewhat more explicit through a brief analysis below.

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179. *See, e.g.*, Holling, *supra* note 158, at 401 (stating that human systems exhibit three unique features: "foresight, communication, and technology").

180. *See* Ruhl & Ruhl, *supra* note 176, at 419 n.27 ("An attractor is simply a model representation of the potential long term behavior of the system, a useful concept for exploring different kinds of long-term behavior. The attractor is not a force of attraction or a goal-oriented presence in the system, but simply depicts where the system is headed based on the rules of motion in the system." (citation omitted)).

181. *See id.* at 418–23.

182. Ruhl, *Thinking*, *supra* note 9, at 945.

183. *See, e.g.*, Ruhl & Ruhl, *supra* note 176, at 421 ("This is known as catastrophe behavior.").

184. *See* Ruhl, *supra* note 156, at 1383 ("Resilience theory does not posit that a system as complex as law is entirely either a vase or a saucer; rather, it is more a set of landscapes over which we find engineering and ecological resilience strategies mixing in different blends to form topographies of various contours depending on where in the system we look. Some resilience theorists refer to this multiscalar complex of topographies as a 'panarchy.'" (footnote omitted)).

The global energy system exhibits self-organization and emergence, meaning that through interactions of its components, the system itself produces properties that cannot be explained through analysis of individual components or as the imposition of an external actor.[185] This type of behavior is apparent in many features of the global energy system, including the market structure that leads to pricing and price fluctuation but also in more fundamental aspects such as the dominance of fossil fuels throughout the system.[186] The role of interaction in creating emergent properties is apparent in several features of energy policy highlighted in Part I, *supra*. The following two processes that created and reinforce fossil fuel dominance in global energy policy suggest an interactive process: (1) the tightly coupled national political and financial reinforcement of fossil fuel dominance, to the point that hundreds of billions of dollars in annual subsidies support fossil fuel dominance; and (2) control of these resources has exhibited an undeniable influence on the shape of overarching global political power relationships (including, but not limited to, empowering oil-rich nations) in ways that were unpredictable, leading to strong international political reinforcement of fossil fuel use and expansion, thus acting to preserve their dominance of fossil fuel energy throughout the globe.[187]

In addition, the global energy system reached its current state through a long series of events that bear the mark of nonlinearity and which provoke changes through flows, primarily of oil and money.[188] The technology of the global energy system, for example, includes some of the most surprising and important inventions and discoveries dating back to the Industrial Revolution.[189] From before the development of electricity through well after the price shocks of the 1970s, the history of the global energy system is punctuated with events that resulted from a confluence of circumstances and created significant leaps forward in the potential for society to meet its material needs and desires,

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185. *See, e.g.*, Kim & Mackey, *supra* note 178, at 7–8.

186. *See id.*; *supra* notes 37–38 and accompanying text.

187. *See supra* Part I.D. These examples are meant to illustrate the type of processes at play, not to provide an exhaustive survey.

188. *See, e.g.*, Sovacool, *supra* note 76, at 4506–09.

189. *See* Kim & Mackey, *supra* note 178, at 9.

which then established a new technological status quo that established the parameters of potential future social and technological paths.[190] Although tracing the threads that have shaped the current system is beyond the scope of this Article, it is notable that features of the energy system are often cited as examples of nonlinear systems behavior.[191]

Although the core premise of this Article requires understanding the global energy system as a complex system, this Article does not take a position on whether it is useful to think of the global energy system as a complex *adaptive* system. There is room for argument about what, specifically, makes a complex system adaptive.[192] Certainly, the resilience of the system and its apparent balance between order and chaos suggest adaptive qualities.[193] However, other hallmarks of adaptability, such as diversity, which Ruhl describes as "the signature of complex adaptive systems,"[194] may be lacking in the global energy system. Indeed, one could argue that it is the lack of diversity represented by the dominance of fossil fuel technologies that prompts the desire to catalyze transformation of the system away from its current state. Thus, to some extent, the degree to which the global energy system is viewed as adaptable may depend on the way in which one defines the system. Viewed narrowly, in terms of the path upon which it has thus far developed, one might wish to emphasize the non-adaptive characteristics of the system because it is precisely those features that should be targeted in transformation efforts (a theme often repeated in the socio-technical literature discussed below). However, viewed broadly, in terms of the system's ability to support social goals and meet human needs, one can understand the system's potential for adaptation as a

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190. *Cf.* Schipper, *supra* note 13, at 87 tbl.1 (summarizing the "historical framing of climate change debate and adaptation thinking" from the 1960s onward).

191. *E.g.*, Ruhl & Ruhl, *supra* note 176, at 444–45 (discussing the apparently random events, including discovery of oil in Texas and the resulting low cost of gasoline, leading to the rise of the automobile in the early twentieth century). *See generally* Felder, *supra* note 9 (analyzing the global energy system as a complex system in greater detail).

192. *E.g.*, Kim & Mackey, *supra* note 178, at 8 ("[Complex adaptive systems] are special cases of complex systems, although the line between them and complex systems is not clear.").

193. *See* Ruhl, *Thinking*, *supra* note 9, at 947.

194. *Id.* at 948–49.

prerequisite to advocating for change. The goal of transformation, after all, is not to destabilize the provision of energy, but merely to change the current state of the system through which such energy is produced and supplied.[195] In this sense, the goal of climate change mitigation efforts is to alter the path upon which the system has, in a self-organizing way, established itself, and to do so in a manner that averts the types of devastating social consequences (such as those discussed in models of extreme climate change or in predictions of peak oil and subsequently dwindling supply) that appear likely to force the system onto another path at some point in the future in order to avoid collapse. In this sense, climate change mitigation may be understood as an effort to speed a process of change that is likely to occur anyway and, by doing so, avoid the most severe consequences of the status quo.

B. THE GLOBAL ENERGY SYSTEM, CLIMATE CHANGE, AND SOCIO-TECHNICAL SYSTEMS

Most environmental law literature that considers complexity theory focuses on its application to natural systems with desirable characteristics, and, by extension, to a system of law designed to promote environmental quality by preventing undesirable transformation of environmental systems.[196] Thus, this literature generally discusses resilience and adaptation as desirable qualities—things to be nurtured in environmental systems and fostered in legal systems that aim to promote environmental quality.[197] While there is recognition that undesirable characteristics or features of a system may be resilient, this possibility is rarely discussed in any depth by environmental law literature, especially as it relates to social (rather than ecological) systems.[198] However, attention to the

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195. *Cf.* Folke, *supra* note 147, at 23 ("[T]ransformability has been defined as 'the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable.'" (citation omitted)).

196. *See, e.g.*, Ruhl, *Thinking*, *supra* note 9, at 941–42.

197. *E.g.*, Craig & Benson, *supra* note 149, at 844 (arguing that "resilience" should replace "sustainability" as a policy goal of environmental law).

198. *E.g.*, *id.* (noting the possibility of resilience in undesirable components without discussing application of the concept of negative resilience to social systems); *see also* Mary J. Angelo, *Stumbling Toward Success: A Story of Adaptive Law and Ecological Resilience*, 87 NEB. L. REV. 950, 1000 (2009) (observing that resilience of ecosystems in undesirable system states may

resilience of undesirable features may have value to environmental law at various scales. For example, at the ecosystem scale it may prove useful for addressing issues such as invasive species. It may also be valuable in understanding undesirable characteristics of global social systems, such as the dominance of fossil fuels in the global energy system and the emergence of climate change. Of course, even high resilience can give way, producing transformation. Although discussions of resilience of undesirable system components rarely receive attention in environmental law literature (and even in ecologically oriented systems literature), another area of literature based on complexity theory has transformation to displace resilient undesirable system components as a primary focus. This literature analyzes "socio-technical systems" by drawing on a complex systems understanding of social forces and technological forces.[199]

Benjamin Sovacool recently noted that "one of the most salient characteristics of modern industrial systems such as telephones and power networks is the degree to which they are not salient for most people, most of the time."[200] For many people, existing technological systems are taken as a given, which obscures their contingent nature.[201] Attention to the socio-technical context of technology, including the interacting social and technical sources of technological constraints, makes explicit the processes and systemic forces that define current

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require management actions to achieve more desirable states). *But see* Ruhl, *supra* note 156, 1381–84 (discussing resilience in the context of the legal system as normatively neutral, noting examples of resilience in undesirable elements such as slavery, and observing that transformation is desirable in some instances).

199. *Cf.* Stephen M. McCauley & Jennie C. Stephens, *Green Energy Clusters and Socio-technical Transitions: Analysis of a Sustainable Energy Cluster for Regional Economic Development in Central Massachusetts, USA*, 7 SUSTAINABILITY SCI. 213, 213–14 (2012) ("The transformation of complex socio-technical systems, and particularly the shift from a fossil fuel-based energy system to one reliant on renewable energy sources, involves a significant re-shaping of regional, place-based infrastructures, economic systems, and social practices."). *See generally* THOMAS P. HUGHES, NETWORKS OF POWER: ELECTRIFICATION IN WESTERN SOCIETY, 1880–1930 (1983) (providing a background for establishing socio-technical theory).

200. Sovacool, *supra* note 76, at 4502 (citing Paul N. Edwards, *Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems*, *in* MODERNITY AND TECHNOLOGY 185–226 (Thomas J. Misa et al. eds., 2003)).

201. *See id.* at 4502–03.

limits and thereby draws attention to the horizon of technological possibility.[202] In environmental law discussions, which often focus on risk and harm prevention, the significant potential for law and policy to affect socio-technical systems in ways that expand this horizon can easily be lost.

The goals of socio-technical systems research include not only to understand the interaction of social and technological systems as a general matter, but also to develop an operational understanding of the relevant processes in order to enable intentional transformation of highly resilient and undesirable aspects of socio-technical systems.[203] The dominance of fossil fuel-based technologies in energy systems is among the primary examples of a resilient undesirable characteristic of socio-technical systems. As one article notes, socio-technical literature often differs from SES literature in that "where existing regimes are judged to be unsustainable, for instance, in energy . . . socio-technical resilience is an undesirable property," and the goal of systemic analysis is to stimulate "radical regime change."[204] Thus, in the language of systems theory more generally, much socio-technical research aims to identify potential pathways for *transformation* of systems with highly resilient and highly undesirable properties.[205] Conceptualizing fossil energy's dominant place in the energy system and the climate change resulting therefrom in this way may provide a fresh perspective on the law and policy questions confronting efforts to address climate change, suggesting that law and policy scholars may draw value from greater attention to socio-technical systems literature.

Most significantly, the concept of "negative resilience" and conceptualizing mitigation as a goal related to transformation of the energy system may prove crucial to developing more effective governance intervention strategies to promote mitigation. As the projections of the IEA and others suggest,

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202. *See id.* at 4503.

203. Adrian Smith & Andy Stirling, *The Politics of Social-Ecological Resilience and Sustainable Socio-technical Transitions*, ECOLOGY & SOC'Y, Mar. 2010, at 11, 14, *available at* http://www.ecologyandsociety.org/vol15/iss1/art11 ("The aim of socio-technical research is thus usually focused on explaining and overcoming this negative resilience." (citation omitted)).

204. *Id.*

205. *See id*; Walker et al., *supra* note 155, at 21 ("Transformation involves changing the state space of the system and the scales of the panarchy.").

there is a very real risk that the dominance of fossil fuels in the global energy system will become even more entrenched and pronounced over the coming decades.[206] As the preceding Parts explained, there are social (including political and economic) reasons for this, and these are reinforced by current technological limitations. Thus, a context-sensitive understanding of the obstacles facing legal and political responses to climate change may be a prerequisite to designing and implementing an effective legal and political mitigation strategy. This strategy must also include attention to the socio-technical system that is a part of the global SES in which climate change has emerged as a severe threat. In other words, greater attention to the process of technological change in society will likely lead to more effective proposals for legal reform.[207]

Although legal literature recognizes that the barriers to technological change represent one of the fundamental differences between the success of the Montreal Protocol and the failure of the Kyoto Protocol, analyses of the issue rarely dig beyond well-known considerations such as the role of economic incentives and the potential for law to operate as a technology forcing mechanism.[208] The socio-technical literature may thus provide an element—in-depth analysis of the interaction between social forces and technical aspects of technological change—that is both essential to addressing climate change and vastly underrepresented in environmental law literature. For example, fossil fuel-based electricity generation presents a paradigmatic example of "strongly embedded, self-reinforcing systems" and has received significant attention in socio-technical research.[209] Recent socio-technical work examining the context for a renewable energy transition in the United States includes an assessment of barriers to renewable electricity[210] and of the emergence of

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206. *E.g.*, IEA FACTSHEET, *supra* note 3, at 1 (predicting that fossil fuels will remain the dominant source of energy through at least 2035).

207. *Cf.* Ruhl & Ruhl, *supra* note 176, at 444–52 (describing the use of technological change as an analogous context for analyzing the law as a complex system).

208. *See generally* Sunstein, *supra* note 76 (demonstrating that the importance of technological considerations is apparent throughout the literature that has compared the Montreal Protocol and the Kyoto Protocol).

209. Smith & Stirling, *supra* note 203, at 13.

210. Sovacool, *supra* note 76.

small-scale clusters of renewable power within communities.[211] Similar research in the United Kingdom provides insights into the role of public perception and reception in a shift from centralized fossil energy and associated policy structures to more heterogeneous and diffuse renewable energy alternatives.[212] Work of this nature holds significant promise for enabling law and policy scholars to better understand the context in which an effective climate change response must operate and, thus, may inform the development of both legal analysis that better accounts for existing extra-legal constraints and concrete policy proposals that have a greater chance of achieving desired results.

The input of law and policy scholars may also prove to be a welcome compliment to existing efforts of socio-technical systems analysis. Much of the socio-technical literature explores how multiscale technological change relates to economic and other social forces without addressing key questions of law and policy design necessary for applying such insights in a way that can catalyze transformation of the energy system.[213] Indeed, some early work attempting to draw on socio-technical theory to facilitate clean energy technology was sharply criticized for relatively simplistic and mechanistic treatment of governance processes.[214] As the field has grown, it

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211. McCauley & Stephens, *supra* note 199.

212. *E.g.*, C. Nolden, *The Governance of Innovation Diffusion—A Socio-technical Analysis of Energy Policy*, 33 EPJ WEB CONFERENCES, art. 01012, at 4–6 (2012), *available at* http://www.epj-conferences.org/articles/epjconf/abs/2012/15/epjconf_e2c2012_01012/epjconf_e2c2012_01012.html (evaluating the United Kingdom's focus in renewable energy such as offshore wind and solar PV).

213. *See* Smith & Stirling, *supra* note 203, at 18–19 (discussing the political (and, implicitly, legal) questions left open by socio-technical systems literature relevant to sustainability and clean energy). *See generally* FRANK W. GEELS, TECHNOLOGICAL TRANSITIONS AND SYSTEM INNOVATIONS: A CO-EVOLUTIONARY AND SOCIO-TECHNICAL ANALYSIS 103–245 (2005) (providing complexity-based analysis of three major technological changes in the eighteenth, nineteenth, and twentieth centuries, along with general conclusions).

214. *E.g.*, Smith & Stirling, *supra* note 203, at 17 ("[C]ritical political dynamics challenge straightforward managerial understandings of transition management." (citation omitted)); *see also* Audley Genus & Anne-Marie Coles, *Rethinking the Multi-level Perspective of Technological Transitions*, 37 RES. POL'Y 1436, 1444 (2008) ("An aspect of this is to consider how, the extent to which, and in what circumstances state organisations and other interested or affected actors affect the diffusion of technology through society.").

has come to provide not only insights into the barriers to technological transition, but also increasingly well-developed models of technological change[215] and a range of relevant case studies that may assist in understanding the conditions through which transition to clean energy technology can occur.[216] Such models and case studies can be seen as offering key information and analytical frameworks for understanding the catalytic role that law can play in technological change on multiple scales, even if much of the current literature lacks sophisticated attention to legal and political analysis to inform reform strategies. In some respects, the insights of socio-technical literature hold a potential value for designing more effective legal tools to achieve mitigation that is similar to what SESs literature offers for adaptation. It may, therefore, offer a particularly relevant and helpful source for environmental law scholars seeking to understand alternatives to the failed approach of the Kyoto Protocol and efforts toward comprehensive U.S. climate change legislation.

IV. FROM COMPLEXITY THEORY TO EFFECTIVE IMPLEMENTATION: GOVERNING THE GLOBAL ENERGY SYSTEM FOR CLIMATE CHANGE MITIGATION

As others have recognized, incorporating concepts from complex systems theory into law and governance presents a significant challenge.[217] The high level of abstraction common

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215. *E.g.*, Adrian Smith et al., *The Governance of Sustainable Socio-technical Transitions*, 34 RES. POL'Y 1491, 1491–92 (2005) (developing a model based on articulation of selection pressures and availability of resources that create an adaptive capacity for regime transition).

216. *E.g.*, Halina S. Brown & Philip J. Vergragt, *Bounded Socio-technical Experiments as Agents of Systemic Change: The Case of a Zero-Energy Residential Building*, 75 TECHNOLOGICAL FORECASTING & SOC. CHANGE 107, 127–28 (2008) (describing the use of small-scale projects to create social receptivity to technological change); Daphne Ngar-yin Mah et al., *Governing the Transition of Socio-technical Systems: A Case Study of the Development of Smart Grids in Korea*, 45 ENERGY POL'Y 133 (2012); Jennie C. Stephens & Scott Jiusto, *Assessing Innovation in Emerging Energy Technologies: Socio-technical Dynamics of Carbon Capture and Storage (CCS) and Enhanced Geothermal Systems (EGS) in the USA*, 38 ENERGY POL'Y 2020 (2010); Rob Wall & Tracey Crosbie, *Potential for Reducing Electricity Demand for Lighting in Households: An Exploratory Socio-technical Study*, 37 ENERGY POL'Y 1021 (2009).

217. *See, e.g.*, *supra* text accompanying notes 175–78.

in complexity theory[218] can make the task appear particularly daunting. While the research-related suggestions articulated above are likely to improve knowledge and enhance the ability to create effective interventions into the global energy system,[219] the urgency and immense stakes of climate change make it particularly important that progress toward a more effective approach moves from theory to practice as quickly as possible.[220] To that end, this Part explores some of the key attributes of reform suggested by viewing climate change as an emergent property of the global energy system.

Energy-related legal reforms aimed at operationalizing complexity theory may be aided by recognition that law itself can be understood as a complex system, which operates within the context of a broader complex governance system, which forms a component of the global energy system, itself a part of broader socio-ecological and socio-technical systems.[221] Likewise, climate change represents alteration of the climate system, which can be understood as a complex system operating as a component of a broader "Earth system," which can also be understood to include the raw materials from which energy is generated (including, but not limited to, fossil fuels). This very broad description of the relevant interacting systems reflects the concept of "panarchy," which describes dynamic processes within and across scales.[222] It serves to illustrate the multiple forces operating in and around the emergence of climate change,[223] which results most directly, of course, from the buildup of GHGs in the atmosphere—a byproduct of the current energy system that affects the climate system in ways that have been increasingly recognized and described by scientists for over a century.[224] Among other reasons, keeping

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218. *See supra* Part II.

219. *See supra* Part III.B.

220. *See generally* PARRY ET AL., *supra* note 43 (discussing predicted climate change impact scenarios).

221. As J.B. Ruhl suggests, "we *must* think of environmental law as a complex adaptive system" in order to address complex environmental issues. Ruhl, *Thinking*, *supra* note 9, at 980.

222. *E.g.*, Holling, *supra* note 158, at 397–98, 401.

223. *See supra* Part II.

224. *E.g.*, *The Carbon Dioxide Greenhouse Effect*, *The Discovery of Global Warming*, AM. INST. PHYSICS, http://www.aip.org/history/climate/co2.htm (last visited Feb. 28, 2014) (describing the history of the science behind climate change).

this broad perspective in mind when developing approaches to mitigation can be helpful because it reminds us that the most analytically simple approach to a specific problem may not be the most desirable course of action and that we will likely fail to achieve desired results if we fail to appreciate the context in which legal reform efforts must operate. In the case of climate change, the most analytically simple approach is probably direct reduction of GHG emissions through specific targets (the Kyoto Protocol's goal), and repeated failures to successfully implement this approach suggest that more contextually-sensitive alternative approaches are necessary to obtain the desired result. Complex systems analysis offers a way of thinking that is highly sensitive to context.

It may also prove useful to briefly consider whether "ecosystem" or "economy," as discussed above,[225] provides a better perspective for governance in this instance. Although the goals of climate change regulation are undoubtedly relevant to (and perhaps only comprehensible in terms of) the broad planetary housekeeping implied by an ecosystem perspective, efforts to impose environmental law controls through the UNFCCC are efforts to inject an exogenous element into the many interacting social and physical systems that create climate change. On the other hand, employing a more "economic" focus on energy governance reforms seeks to promote changes to a human-imposed ordering (the energy system) that interacts with broader ecosystem forces, and the likelihood of prompting ripple effects throughout the human-created energy system may be more readily assessed. Focusing on energy governance rather than environmental harm may thus help to understand the components subject to potential policy action, as well as their interconnection with other components of the system. Rather than imposing an alternative framing of the issue (environmental harm), reforms that conceptualize the energy system as a human-imposed ordering of social and economic concerns may have the benefit of focusing on modifications to existing arrangements within the system that are most relevant to directing human behavior (such as the relationship of various political interests in the

225. *See supra* text accompanying notes 52–54.

energy system to other politically important interests that may affect the ability to secure legal reforms).[226]

With these broad points in mind, the remainder of this Part suggests that reforms may be most helpful to catalyzing energy system transformation if they focus on: (1) framing goals to secure political support; (2) reforming structural arrangements to support technological transformation; and (3) promoting interaction—among components of the energy system and with components of related systems—that produces beneficial effects for the communities involved while tending to encourage transformation of the global energy system as a whole. These elements of reform are discussed briefly below.

A. SIMPLE COMPLEXITY: POLITICAL AND IMPLEMENTATION CONSIDERATIONS

Situating law and governance in systems terms—as components of overlapping systems that operate across multiple geographic and jurisdictional scales while intersecting with various other policy spaces—highlights the need to remain mindful of the interaction of each element of the governance system with other governance system components and with components of other systems. In a sense, it provides an appropriately humble position from which to observe the global political interaction that ultimately determines whether governance regimes are created and reformed. Thus, it may be that complexity theory appropriately "inculcates a sense of uncertainty" in global political analysis.[227] Policy proposals drawn from complexity theory, which try to account for and manage uncertainty, also tend to be relatively complex.[228] For example, the authors of the introduction to a special issue of the journal *Global Environmental Change* on governing complex SESs suggest that existing literature firmly supports

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226. *Cf. supra* Part I.D.3 (discussing the issues related to energy governance and geopolitics).

227. Neil E. Harrison, *Complex Systems and the Practice of World Politics*, *in* COMPLEXITY IN WORLD POLITICS: CONCEPTS AND METHODS OF A NEW PARADIGM 183, 193 (Neil E. Harrison ed., 2006) ("[The complexity] paradigm can increase our understanding of the complexity of world politics and reduce the probability of surprising events.").

228. For an example of a policy proposal to manage uncertainty, see Alejandro E. Camacho, *Adapting Governance to Climate Change: Managing Uncertainty Through a Learning Infrastructure*, 59 EMORY L.J. 1, 64–76 (2009).

the notion that "in order to govern processes of complex change, complexity in the external world must be matched by complexity in the governance system."[229] They point to concepts such as polycentric governance and adaptive governance, as well as literature on network governance and other relatively flexible approaches, as evidence of the concept's broad acceptance among scholars.[230]

Although both governance and political processes may be accurately described by complexity analysis, success in politics (domestically and, ultimately, globally) also requires gaining widespread public support, particularly for the creation or reform of mechanisms aimed at addressing controversial topics like climate change.[231] In part, the ability to gain favorable public opinion depends upon the information costs (or mental effort) required to understand the issues at stake and the proposals for which support is sought, as well as their alignment with existing political arrangements.[232] Following the principle of least effort, the human mind very often operates like a reductionist machine that simplifies information to reduce the effort of understanding it.[233] Although it is certainly possible for people to grapple with complexity, many seem to avoid it whenever possible.[234] In the context of climate policy, for example, social science evidence suggests that people apply heuristic processing and align their views with political elites rather than incur the information costs (or apply the mental effort) to understand the scientific

229. Duit et al., *supra* note 136, at 365.

230. *Id.* at 365–67 (describing various articles on the issue).

231. *E.g.*, Cynthia R. Rugeley & John D. Gerlach, *Understanding Environmental Public Opinion by Dimension: How Heuristic Processing Mitigates High Information Costs on Complex Issues*, 40 POL. & POL'Y 444, 445–46 (2012) (collecting literature on public opinion in the political process).

232. *Id.* at 463.

233. DANIEL KAHNEMAN, THINKING, FAST AND SLOW 38 (2011) (observing that people "normally avoid mental overload by dividing our tasks into multiple easy steps" and "conduct [their] mental lives by the law of least effort").

234. *Id.* at 45 ("[M]any people . . . . apparently find cognitive effort at least mildly unpleasant and avoid it as much as possible."). The bio-psychological reasons for this appear to have an evolutionary origin. *Id.* at 35 (discussing the positive emotional state triggered by cognitive ease as an evolutionarily important biological signal). Although outside the scope of this Article, it is interesting to consider how this perspective may help in understanding why law and policy have historically been so reductionist.

information necessary for an informed opinion.[235] Therefore, reforming energy policy on the basis of insights derived from complexity theory will require presenting such proposals in terms that are either readily accessible to the public or, more likely, capable of gaining support from influential leaders. Achieving such support on the global level, outside the context of a pre-existing issue regime, poses a substantial obstacle that will likely require context-specific analysis in order to achieve concrete reforms in specific places or sectors.[236] Although a full discussion is outside of the scope of this Article, consideration of key elements of a global approach can be identified and briefly discussed. The first aspect of a global approach is the identification of relatively clear goals that can guide reform efforts and gain political support.

B. Goal of Reform: Catalyzing Technological Transformation

The core purpose of reform as envisioned by this Article is to reduce GHG emissions, and thereby mitigate climate change, by dislodging the dominant place of fossil-fuel-dependent technologies in the global energy system.[237] The more rapidly, decisively, and completely this transformation can occur (without harmful social destabilization), the better. If one looks at energy policy in traditional environmental or international law terms (i.e., as the subject of traditional political science and international relations analysis), the challenge may seem overwhelming.[238] From any perspective, it is daunting. But complexity offers a lens through which rapid wholesale transformation of the GHG-belching engines that drove the Industrial Revolution into low-GHG clean tech for the

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235. *Cf.* Rugeley & Gerlach, *supra* note 231, at 448–49 ("[I]n an effort to mitigate [ ] information costs, citizens look to their political affiliations and the media when forming public opinions on climate change."). This type of psychological simplification may also offer some explanation for why environmental governance remains so reductionist and fragmented despite the rising chorus of scientific and scholarly voices advocating adoption of approaches that are better suited to environmental systems. *See supra* note 213 and accompanying text.

236. *See supra* Part I.C.

237. Clearly, this goal is likely to incite opposition from fossil fuel interests, *see, e.g.*, Am. Petroleum Inst. v. Envtl. Prot. Agency, 706 F.3d 474, 476 (2013), which simply enhances the need for public support.

238. *See supra* Part I.D.

information age becomes *possible*, but by no means certain, in a way that appears inconceivable through a continuation of the UNFCCC or other harm-focused approaches.[239] In other areas of environmental law, focusing squarely on the environmental harm as a basis for reforms has frequently created a dynamic in which legal regimes arise as reactions to a specific crisis that triggers public and political responses.[240] Following that course in the climate context, as UNFCCC negotiations and much of U.S. political discourse seems to be doing, may mean that major social and economic disruption—perhaps even catastrophe in the complex systems sense—will be required before any meaningful legal response to climate change arises on the global scale. A complexity perspective targeted toward the global energy system offers a real alternative mode of analysis that may reveal pathways to transformation that averts the type of crises that have driven past environmental law creation. Yet, by its very nature, the details of transformation in a complex system cannot be fully predicted or planned in advance. Whatever dream there might have been for a grand global environmental regime implementing a plan that charts a course to a future of universal environmental sustainability is over and it should not be resurrected in the guise of complexity. Instead, with an appreciation of context in mind, the specific goals of reform should be formulated through a broad and flexible approach to focus on promoting changes on relatively small scales in ways that hold a potential to begin a larger process of transformation.

The path toward energy system reform that complexity suggests is far messier than an efficient and centralized multilateral environmental regime modeled on the Montreal Protocol (although it does not prevent the formation of Montreal-like regimes where the conditions are right for them

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239. *See supra* Part I.

240. *See, e.g.*, William L. Andreen, *The Evolution of Water Pollution Control in the United States—State, Local, and Federal Efforts, 1789–1972: Part I,* 22 STAN. ENVTL. L.J. 145, 151 (2003) (observing that legislation and other progress in protection of water quality "has often been driven by some sort of crisis or series of events that thrusts an issue to the forefront of political attention," which results in "reactive decision-making" that may be "short-sighted, geared to the political necessity of addressing a single, highly charged issue").

to flourish).[241] Instead, complexity theory suggests that whatever hope remains for mitigating climate change at or near the 2° target discussed in the UNFCCC context[242] and by the IPCC[243] will only be achieved, if at all, through actions that accrete and trigger reactions, expanding in a nonlinear fashion similar to the dynamics that have created widespread concern over catastrophic climate change impacts beyond certain "tipping points."[244] The question for policymakers seeking to employ complexity insights must be framed in terms of measures that can set in motion and maintain systemic forces that will result in technological transformation through systems dynamics.[245] In other words, while environmental law has sought to prevent systemic change through restraints on the inputs into physical or ecological systems, the goal of rapid technological transformation will only be realized through changes to the energy system components in ways that unleash systemic change forces in the global energy system.

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241. In fact, it has been argued that the evolution of the Montreal Protocol reflects complex adaptive systems properties. Matthew J. Hoffmann, *Beyond Regime Theory: Complex Adaptation and the Ozone Regime*, *in* COMPLEXITY IN WORLD POLITICS: CONCEPTS AND METHODS OF A NEW PARADIGM 95, 108–11 (Neil E. Harrison ed., 2006). "Messy" is used here in the sense that J.B. Ruhl describes in *Thinking of Environmental Law as a Complex Adaptive System*. Ruhl, *Thinking*, *supra* note 9, at 983 (describing environmental law reform as "local, state, and federal structures [combining] their 'genes,' engag[ing] in the political equivalent of sex, and mak[ing] the environmental law governance system messy in the complex adaptive systems sense").

242. *The Cancun Agreements*, UNFCCC, http://cancun.unfccc.int/cancun-agreements/significance-of-the-key-agreements-reached-at-cancun/ (last visited Feb. 28, 2014).

243. Peter Frumhoff, *2° C or Not 2° C: Insights from the Latest IPCC Climate Report*, UNION CONCERNED SCIENTISTS (Sept. 27, 2013), http://blog.ucsusa.org/2-c-or-not-2-c-insights-from-the-latest-ipcc-climate-report-255.

244. For a discussion of "tipping points" and climate change, see Robert Sanders, *Report Warns of Climate Change "Tipping Points" Within Our Lifetime*, UC BERKLEY NEWS CENTER (Dec. 3, 2013), http://newscenter.berkeley.edu/2013/12/03/report-warns-of-climate-change-tipping-points-within-our-lifetime/.

245. *E.g.*, Farber, *supra* note 138, at 152–53 (discussing the more unusual situation of power laws, wherein "immeasurable variations in the current state of affairs can lead over time to arbitrarily large divergences in eventual outcomes"); Ruhl, *Thinking*, *supra* note 9, at 952 (describing the process by which relatively small changes in the governance status quo may reverberate through the system in ways that, over time, lead to a massive change or even a transformation of the system).

The concept of governance changes designed to promote systemic change forces leading to a desirable outcome in partly social systems has no apparent analogue in practice and has just begun to appear in the literature.[246] The approach is discussed as "applied forward reasoning" in a recent article by Levin et al., which begins to establish a framework for examining specific situations based on a "reverse" application of what is known about path dependency.[247] The authors suggest that exploring potential pathways through a sort of reverse path dependency logic may enable some assessment of the likelihood that particular policy changes will lead to desirable, large-scale systemic transformation.[248] Developing applied forward reasoning or other in-depth analysis to identify specific measures that can support the type of transformation envisioned here may significantly reduce the uncertainty of efforts to promote transformation of the global energy system, bringing the goal more clearly within reach.

Two general policy targets help to clarify the types of actions likely to advance the broader goal of dislodging fossil energy's dominance: technological innovation and technological diffusion. These can be employed like a "rule of thumb," such that they offer a direction in which policy reforms can attempt to move. Thus, taking actions that facilitate technological innovation in as many contexts and potentially viable forms as possible increases the chances of opening up the technological horizon of possibility and achieving significant technological breakthroughs. For example, promoting small-scale clean energy projects around the globe through development aid and policies of investment institutions serves to establish "laboratories" for experimentation to address the technical challenges of clean energy.[249] Secondly, institutional arrangements and legal rules that affect technological diffusion

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246. It must be said, however, that J.B. Ruhl's work in the late 1990s strongly suggests such an approach and, in that sense as well as others, serves as a forerunner of most of the other literature and conceptual developments discussed in this Article. *E.g.*, Ruhl, *Thinking*, *supra* note 9, at 952.

247. Kelly Levin et al., *Overcoming the Tragedy of Super Wicked Problems: Constraining Our Future Selves to Ameliorate Global Climate Change*, 45 POL'Y SCI. 123, 130–38 (2012).

248. *Id.* at 138–47.

249. *Cf.* New State Ice Co. v. Liebmann, 285 U.S. 262, 311 (1932) (Brandeis, J., dissenting) (discussing "laboratories" for experimentation in the context of states).

(such as intellectual property rights laws) can be examined with an eye toward revision that will pave the way for rapid diffusion of significant technological advances. As Oran Young suggested in the context of environmental institutions analysis: "There is much to be said, under the circumstances, for thinking systemically about institutional options in advance, so that well-crafted options are available when crises open up windows of opportunity for the introduction of substantial institutional changes."[250] The same principle applies to technological transformation and the mitigation challenge. If circumstances, such as a price spike in fossil fuels, correspond with technological change sufficiently to enable large-scale change, it will be crucial to have governance arrangements in place that can facilitate rapid and effective diffusion of alternative technologies in order to maximize the opportunities created. These goals suggest the need for attention to governance relationships that, while perhaps far looser than traditional environmental law regimes, can create an over-arching structure to facilitate movement toward a significantly lower GHG energy system.

C. POLYCENTRIC GOVERNANCE RELATIONSHIPS

Polycentric governance literature, particularly when understood as an application of complexity concepts to governance,[251] suggests that challenges as complex and global as climate change will require multiple layers of governance that are designed to promote flexible experimentation and cooperative learning, in line with the goals discussed above.[252] The multiscalar nature of energy governance, as it currently exists, could become an asset by incorporating elements from both top-down systems and bottom-up efforts to allow small-

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250. Oran R. Young, *Institutional Dynamics: Resilience, Vulnerability and Adaptation in Environmental and Resource Regimes*, 20 GLOBAL ENVTL. CHANGE 378, 384 (2010).

251. Although polycentric governance literature is not usually explicitly tied to complexity concepts, the similarities are striking, particularly with regard to self-organization and the apparent design of polycentric governance structures to promote emergence through the interaction of various authorities within a larger governance arrangement. Consider, for example, the climate change governance strategy articulated in Ostrom, *supra* note 17, at 551.

252. *See supra* text accompanying notes 249–50.

scale experimentation and facilitate global learning.[253] In practical terms, this means enlisting "higher" scales of governance (e.g., international) to facilitate finance for specific clean energy projects and, equally important, to collect and transmit lessons learned from them to future projects. Moreover, it offers an opportunity to create guidance at the global or international level that can promote energy system improvements by fostering innovative and semi-autonomous efforts at smaller-scales, perhaps through aligning funding conditions with the global social and environmental priorities that can promote multi-issue initiatives, including the goal of technological innovation that may begin to trigger broader changes in the system as experience accumulates.[254] To be effective, such arrangements will need to occur in a context that creates trust among participants and enables productive interaction, such as information sharing and technology diffusion.[255]

D. LINKAGES AND INCENTIVES

Coordination of efforts across multiple scales throughout the planet is not likely to simply self-organize for reasons similar to those that have stalled UNFCCC efforts to fail. Chief among these is the lack of incentives for many actors to accept short-term individualized costs solely to promote a widely shared future benefit.[256] Accordingly, promoting innovation,

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253. *See* Underdal, *supra* note 123, at 389–92 (noting different models for collective action); *see also* Osofsky, *supra* note 2, at 241 (arguing that addressing climate change policy requires resolution of "regulatory problems that intersect with every level of government, from the most local to the most global").

254. In a similar vein, Sovacool suggests that polycentric approaches to governance, which he describes as "so complex that there is no guarantee . . . [of] optimal forms of governance," "can offer an equitable, inclusive, informative, accountable, protective, and adaptable framework" for addressing the panoply of social and environmental challenges involved in governing the global energy system. Benjamin K. Sovacool, *An International Comparison of Four Polycentric Approaches to Climate and Energy Governance*, 39 ENERGY POL'Y 3832, 3842 (2011).

255. *See generally* Elinor Ostrom, *A Polycentric Approach for Coping with Climate Change* 38–39 (World Bank Policy Research, Working Paper No. 5095, 2009), *available at* http://www.iadb.org/intal/intalcdi/pe/2009/04268.pdf (recommending a multilevel approach to achieve emissions reduction).

256. *Cf. supra* note 17 and accompanying text (noting the traditional theories used to solve collective-action problems).

especially diffusion of technology, will likely depend heavily upon the creation of appropriate incentives through financing and, importantly, linkage with other significant social priorities in particular geographic areas. The highly interconnected nature of many issues related to energy creates an opportunity to promote local priorities while also advancing global climate change goals. Moreover, these considerations strongly caution against a "single-minded" pursuit of one objective (such as mitigation) to the exclusion or detriment of others (such as biodiversity preservation or well-being of affected communities). These concepts have been discussed, to some degree, in international environmental law literature, especially work related to mitigation in the land use and forestry sectors that advocates consideration of multiple issues in the design of programs and reform of legal rules.

Many current REDD+ efforts in the forestry context have begun to explore incorporation of climate, biodiversity, and human development goals into holistic efforts.[257] This is in stark contrast to many of the existing incentives of investment into developing countries for the purposes of meeting rising demand,[258] as well as many of the international environmental law regimes.[259] Understanding the multiple interacting components of the global energy system can provide practical guidance by highlighting the value of considering the multiple forces that define a particular context. Clean energy projects that are integrated with other priorities in specific contexts, such as national or local agricultural or livelihood concerns, may produce more robust results.

The Brazilian transition to ethanol in the 1970s–80s illustrates this point and could serve as a model of sorts for

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257. For a related analysis in the context of forestry emissions, see Long, *supra* note 34, at 163 ("[These approaches] would overcome the fragmentation and persistent divisions that have plagued prior efforts to address key environmental issues . . . ."). For a discussion in the biodiversity context, see generally Arnold, *supra* note 125, at 798 (describing the characteristics of complex environmental problems and suggesting that they "demand that environmental law and policy become increasingly integrationist and multimodal"); *see also* Andrew Long, *Developing Linkages to Preserve Biodiversity*, 21 Y.B. INT'L ENVTL. L. 41, 58–66 (2011).

258. Florini & Sovacool, *supra* note 68, at 66 ("[F]unding on energy continues to support traditional centralized fossil fuel plants.").

259. Long, *supra* note 257, at 42–43 (discussing fragmentation of international environmental law).

similar efforts on smaller scales.[260] In Bangladesh, attention to local livelihood needs and development of innovative financing has enabled a broadly successful nonprofit effort to promote small-scale renewable technologies that have significantly reduced deforestation and provided direct health benefits to the local population.[261] Conceiving of the mitigation challenge as a problem of reducing fossil fuel dominance in the global energy system, with appropriate attention to the multiplicity of interacting components to that system, supports developing internationally applicable incentives for projects of this type and, of equal importance, of developing the learning infrastructure to allow them to be replicated and, where possible, scaled-up.

V. CONCLUSION

Thinking about energy as a complex system from which fossil fuel dominance and climate change emerge provides an analytical and policy-relevant framework for exploring pathways toward transforming that system. The linkage of issues and scales of authority, highlighted briefly above, are but two examples of how this might be operationalized.[262] Literature since the 2009 UNFCCC negotiations in Copenhagen is beginning to explore alternatives to top-down binding international environmental agreements for catalyzing successful mitigation, but it has yet to coalesce around an analytical framework that can foster synergy and the development of a cohesive body of work identifying and testing viable options that are likely to produce solid policy recommendations. A perspective on climate change informed by an understanding of the global energy system as a complex system has the potential to provide such a framework.

Further exploring the potential for an interdisciplinary perspective on energy as a complex system may provide the

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260. *See* Sovacool, *supra* note 254, at 3837–38 (discussing benefits of the transition for workers and for soil productivity).

261. *Id.* at 3838–39.

262. Another possibility for affecting systemic forces is the reduction of fossil fuel subsidies (or introduction of taxes or other pricing mechanisms) to reduce the market distortions supporting fossil fuel dominance, which may become more politically feasible as technological development reduces the cost of alternatives. Roberta F. Mann & Mona L. Hymel, *Moonshine to Motorfuel: Tax Incentives for Fuel Ethanol*, 19 DUKE ENVTL. L. & POL'Y F. 43, 79 (2008).

analytical framework needed to accelerate the learning process by uniting the somewhat disparate strands of thought that have emerged since the "dream of Rio," characterized by an unjustified faith in global top-down environmentalism, came to a crashing halt at the end of 2009. A complexity perspective on energy as the source of climate change may unite many of the developing approaches, which include work exploring near-term approaches to climate change mitigation,[263] detailed analysis of particular aspects of the mitigation challenge if developed outside of a unifying top-down structure,[264] and analytical expositions of polycentric governance theories in climate-relevant ways.[265] Viewed as a body of literature addressing facets of a global complex systems challenge, such work can be understood to contain the seeds of an approach that is sufficiently salient to garner political support while also probing for effective tools that will engage the multiple interacting threads of social, ecological, and technical components that affect the energy system across scales in order to produce an overall shift that achieves climate stabilization.

There is much work to be done if we hope to bring about the kind of transformation of the global energy system necessary to reduce GHG emissions significantly and rapidly enough to avoid drastic climate change impacts. A complexity perspective strikes an appropriate balance between resigning the global population to the massive suffering and destabilization that climate change may bring, as a narrow focus on developed country adaptation would do, and the unwarranted faith in top-down global governance that much of the previous decade's climate change analysis exhibited. In this sense, a complexity perspective on climate change urges a form of governance reflecting the nature of adaptive systems situated on the edge of chaos—advocating enough order to avert disaster, while imbuing reform with the long-term catalytic vision necessary to bring about the emergence of that which is desirable, but remains uncertain and unpredictable.

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263. *E.g.*, Richard B. Stewart et al., *Building Blocks for Global Climate Protection*, 32 STAN. ENVTL. L.J. 341, 343–44 (2013).

264. *E.g.*, Boyd, *supra* note 13, at 471–72.

265. *E.g.*, Elinor Ostrom, *Nested Externalities and Polycentric Institutions: Must We Wait for Global Solutions to Climate Change Before Taking Actions at Other Scales?*, 49 ECON. THEORY 353, 355 (2010); Sovacool, *supra* note 254, at 3835–40.

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