Sustainable Development: A Five-Dimensional Algorithm for Environmental Law

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I. INTRODUCTION

Environment, economy, and social equity are not mutually exclusive, hermetically sealed spheres of life. Problems such as envi-

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ronmental degradation, economic collapse, and widening disparities in living conditions are the result of complex, coevolving interactions between environmental, economic, and social forces; they find their lasting solutions only when these three domains can be sensibly harmonized over time and space. To the extent that we hope to design laws that assist in the resolution of such problems, we should employ this ideal conception of a timeless, spatially seamless fusion—not separation—of environment, economy, and equity.[1]

Environmental law has nonetheless developed over the past three decades as if the economy is its enemy and equity a sideshow. Recent overtures to market-based regulatory programs[2] and environmental justice[3] are too little, too late, to cure this legacy. En-

1. For more extensive expositions on the design of law, particularly environmental law, to reflect a holistic, systems-level focus, see J. B. Ruhl, *The Fitness of Law: Using Complexity Theory to Describe the Evolution of Law and Society and Its Practical Meaning for Democracy*, 49 VAND. L. REV. 1407 (1996) [hereinafter Ruhl, *Fitness of Law*]; 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 of Environmental Law*].

2. The need for greater reliance on market forces to bring about more efficient protection of environmental conditions has been forcefully argued by many commentators for over a decade. *See, e.g.*, Bruce A. Ackerman & Richard B. Stewart, *Reforming Environmental Law: The Democratic Case for Market Incentives*, 13 COLUM. J. ENVTL. L. 171, 171 (1988) (arguing that the creative use of market incentives will save billions of dollars each year, alleviate bureaucratic inefficiency, help balance the budget, and encourage a more democratic debate by providing the public with a greater opportunity to express its environmental values); Robert W. Hahn & Gordon L. Hester, *Marketable Permits: Lessons for Theory and Practice*, 16 ECOLOGY L.Q. 361, 364-65 (1989) (stating that marketable permits have the potential to make environmental policy more efficient); Robert W. Hahn & Robert N. Stavins, *Incentive-Based Environmental Regulation: A New Era from an Old Idea?*, 18 ECOLOGY L.Q. 1, 10-11 (1991) (noting that "substantial gains can be made in environmental protection simply by removing existing government-mandated barriers to market activity"); Jeremy B. Hockenstein et al., *Crafting the Next Generation of Market-Based Environmental Tools*, ENV'T, May 1997, at 13, 15 (arguing that the two most notable advantages to market-based instruments are cost-effectiveness and incentives for technological innovation). The Clean Air Act sulfur dioxide emissions trading program instituted in 1990 for electric utilities, 42 U.S.C. §§ 7651-7651o (1994), was the first major attempt to put market-based environmental measures into practice, and is now widely regarded as a resounding success. *See, e.g.*, Dallas Burtraw & Byron Swift, *A New Standard of Performance: An Analysis of the Clean Air Act's Acid Rain Program*, 26 ENVTL. L. REP. 10,411, 10,411 (1996); Byron Swift, *The Acid Rain Test*, ENVTL. F., May-June 1997, at 17 (reporting that the 1990 Clean Air Act's Acid Rain Program has significantly decreased the amount of sulfur dioxide emissions produced by public utilities).

3. Environmental justice refers to the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." U.S. Envtl. Protection Agency, Office of Federal Activities, *Final Guidance for Incorporating*

vironmentalism is to blame for this policy myopia. Environmentalism is dead. Long live sustainable development.

Heresy? Maybe. For many, however, environmentalism is a worn-out label, its permutations found in a sea of bumper sticker slogans and self-righteous, self-anointed "environmentalists."[4] What is an environmentalist today? What must one believe in order to join the club, and who decides the qualifications? If the vast majority of Americans consider themselves environmentalists, does the label still serve to distinguish?[5] Perhaps a new label is

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Environmental Justice Concerns in EPA's NEPA Compliance Analyses (visited Oct. 19, 1998) <http://es.epa.gov/oeca/ofa/ejepa.html>.

The topic of environmental justice, and whether injustice truly exists, has exploded in the last decade into legal and social commentary. *See, e.g.*, KENNETH A. MANASTER, ENVIRONMENTAL PROTECTION AND JUSTICE (1995); DAVID E. NEWTON, ENVIRONMENTAL JUSTICE: A REFERENCE HANDBOOK (1996); Symposium, *Race, Class, and Environmental Regulation*, 63 U. COLO. L. REV. 839 (1992); Gerald Torres, *Environmental Burdens and Democratic Justice*, 21 FORDHAM URB. L.J. 431 (1994). For thorough bibliographies of the law, commentary, and legal materials pertaining to the environmental justice issue, see Adam D. Schwartz, *The Law of Environmental Justice: A Research Pathfinder*, 25 ENVTL. L. REP. 10,543 (1995) and Carita Shanklin, *Pathfinder: Environmental Justice*, 24 ECOLOGY L.Q. 333 (1997). There are also now a number of governmental programs designed to identify and address instances of alleged environmental injustice. *See, e.g.*, Exec. Order No. 12,898, 59 Fed. Reg. 7629 (1994) (directing executive agencies to develop strategies for identifying and addressing instances of environmental injustice affecting minority and low-income groups); U.S. Envtl, Protection Agency, *The EPA's Environmental Justice Strategy: Executive Order 12,898*, (last modified Apr. 3, 1995) <http://www.epa.gov/docs/oejpubs/strategy/strategy.html> (explaining how EPA intends to implement Executive Order No. 12,898); Office of Enforcement & Compliance Assurance, U.S. Envtl. Protection Agency, *Interim Guidance for Investigating Title VI Administrative Complaints Challenging Permits* (last modified Feb. 13, 1998) <http://es.epa.gov/oeca/oej/titlevi.html> (explaining how EPA will investigate claims alleging discrimination in the issuance of environmental pollution permits by state and local agencies).

4. *See* Daniel C. Esty & Marian R. Chertow, *Thinking Ecologically: An Introduction* to THINKING ECOLOGICALLY 4, 4-6 (Daniel C. Esty & Marian R. Chertow eds., 1997) (suggesting the new term "ecologicalism" to depart from the environmentalism label and capture the spirit of sustainable development).

5. Public opinion polls show that Americans who say they care about the environment have grown in number steadily through 1991, to over 60% of the population, and have plateaued at a level at which environmentalism can be considered "mainstream." Nevertheless, only a small fraction of these "environmentalists" actively make environmentalism their way of life through dedicated recycling, composting, water conservation, xeriscape, and so on. *See* Tibbett L. Speer, *Growing the Green Market*, AM. DEMOGRAPHICS, Aug. 1997, at 45-49; Peter Stisser, *A Deeper Shade of Green*, AM. DEMOGRAPHICS, Mar. 1994, at 24-29; Traci Watson, *For Most Americans, It's Not Easy Being Green*, USA TODAY, Apr. 22, 1998, at 3A. Some commentators find the mainstreaming of American environmentalism a disturbing indication that environmentalists have "caved in" to economic development interests, against which they call for the emergence of a radical, new, uncompromising environmental movement to regain the ground they perceive has been lost. *See generally* MARK DOWIE, LOSING GROUND (1995).

needed—one that corresponds to the vision of a unified approach to environment, economy, and equity.

A. *Background: The Environmentalism-Resourcism Dichotomy*

Environmentalism was useful as a basis from which to identify, isolate, and undermine its antithesis, resourcism,[6] in a struggle between collective and private interests relating to the environment and the economy.[7] Whereas resourcism sought to collectivize the costs of environmental degradation and capture the economic benefits of resource use for private gain,[8] environmentalism sought to reveal the collective benefits of environmental quality and the degree to which resourcism's uncaptured externalities threatened delivery of those common benefits.[9] In the end, however, environmentalism learned its lesson well from resourcism, by simply collec-

6. I use the term "resourcism" as a shorthand for the policy position that advocates reliance on free-market forces as the principal mechanism for directing resource consumption and environmental protection policies, based on the theory that resource owners will be driven by the profit motive to balance resource exploitation and conservation at economically efficient levels over the short- and long-run. One of the leading advocates of this approach was the late economist Julian Simon, who contended that technological advances, spurred by the profit motive, would prevent rising consumption from depleting and destroying natural resources. See generally JULIAN L. SIMON, THE ULTIMATE RESOURCE (1981); Julian L. Simon, *Resources, Population, Environment: An Oversupply of False Bad News*, 208 SCI. 1431 (1980). For more current versions of the theory, see, e.g., TERRY L. ANDERSON & DONALD R. LEAL, FREE MARKET ENVIRONMENTALISM (1991).

7. *See* J. Baird Callicott & Karen Mumford, *Ecological Sustainability as a Conservation Concept*, CONSERVATION BIOLOGY, Feb. 1997, at 32, 34 (identifying "resourcism" and "preservationism" as philosophies that dominated the first three quarters of the twentieth century); Marc R. Poirier, *Property, Environment, Community*, 12 J. ENVTL. L. & LITIG. 43, 43-45 (1997) (identifying the roots of the "property rights encomium" and the "environmental jeremiad").

8. *See* Callicott & Mumford, *supra* note 7, at 38 (noting that classic resourcism is "reductive and ignores nonresources").

9. The most prominent treatment of this topic is Garret Hardin's classic theory of the tragedy of the commons, which exposes the irrational collective use of common resources brought about through the rational, individual economic decisions of the resource's multiple users. *See* Garret Hardin, *Extensions of the Tragedy of the Commons*, 280 SCI. 682 (1998); Garret Hardin, *The Tragedy of the Commons*, 162 SCI. 1243 (1968). Equally as influential has been the Pigouvian school of welfare economics, which debates the use of regulations, taxes, and other market interventions, to "internalize" spillover effects to produce more efficient allocations of resource use. *See* DAVID MALIN ROODMAN, THE NATURAL WEALTH OF NATIONS 148-50 (1998); A.W. Brian Simpson, *Coase v. Pigou Revisited*, 25 J. LEGAL STUD. 53 (1996) (outlining Pigouvian externality theory). Extensions of externality theory also figure prominently in modern environmental law literature. *See, e.g.*, Henry N. Butler & Jonathan R. Macey, *Externalities and the Matching Principle: The Case for Reallocating Environmental Regulatory Authority*, 14 YALE J. ON REG. 23 (1996); Richard L. Revesz, *Federalism and Interstate Environmental Externalities*, 144 U. PA. L. REV. 2341 (1996); Mark Sagoff, *Economic Theory and Environmental Law*, 79 MICH. L. REV. 1393 (1981); Matthew Tuchband, *The Sys-*

tivizing the benefits of environmental preservation and privatizing its costs, an approach that has only fanned the fires of die-hard resourcism.[10]

Yet the world is simply too complex to allow either resourcism or environmentalism to survive as relevant policies. American resourcism depended on consumption levels that cannot possibly be replicated throughout the world.[11] American environmentalism produced the Endangered Species Act,[12] a law of tremendous power, but of absolutely no relevance to, for example, the problem of deforestation in western India where basic human survival needs spare no ecosystem, much less an endangered species.[13] A new approach is needed. That approach is sustainable development.

B. *Overview: Sustainable Development's New Approach*

What is sustainable development? To the disappointment of many resourcists and environmentalists, sustainable development is neither resourcism, nor environmentalism, nor a Solomonic compromise between the two. Rather, as Part II of this Article explores, sustainable development defines all social problems in terms of three parameters—environment, economy, and equity—and projects them in the dimensions of geographic scale and

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temic Environmental Externalities of Free Trade: A Call for Wiser Trade Decisionmaking, 83 GEO. L.J. 2099 (1995).

10. The visceral evidence of this approach taken to an extreme is today called the "wise use" property rights rebellion, which generally blames environmentalism for all economic and social problems. *See generally, e.g.*, RON ARNOLD & ALAN GOTTLIEB, TRASHING THE ECONOMY (2d ed. 1994) (citing a manifesto from the movement's informal founders); LAND RIGHTS: THE 1990S' PROPERTY RIGHTS REBELLION (Bruce Yandle ed., 1995); JACQUELINE VAUGHN SWITZER, GREEN BACKLASH: THE HISTORY AND POLITICS OF ENVIRONMENTAL OPPOSITION IN THE U.S. (1997) (discussing the history and emergence of the wise use movement). These extreme resourcists have managed to reshape mainstream politics to the point that prized accomplishments of die-hard environmentalists, such as the Endangered Species Act, are threatened. *See* J. B. Ruhl, *Section 7(a)(1) of the "New" Endangered Species Act: Rediscovering and Redefining the Untapped Power of Federal Agencies' Duty to Conserve Species*, 25 ENVTL. L. 1107, 1137-42 (1995). Indeed, much of the literature covering the wise use movement emanates from groups closely associated with extreme environmentalism who deride these "wise users" at every opportunity for their effect on the environmentalists' agenda. *See generally, e.g.*, LET THE PEOPLE JUDGE (John D. Echeverria & Raymond Booth Eby eds., 1995).

11. *See* Norman Myers, *Consumption in Relation to Population, Environment and Development*, 17 ENVIRONMENTALIST 33, 34-37 (1997); Arnold W. Reitze Jr., *Population, Consumption, and Environmental Law*, 12 NAT. RESOURCES & ENV'T 89, 92, 141-43 (1997).

12. *See* 16 U.S.C. §§ 1531-1544 (1994).

13. *See* T.I. Khan, *Conservation of Biodiversity in Western India*, 17 ENVIRONMENTALIST 283, 285 (1997) (In the Thar desert, "[t]rees, shrubs and even their roots are mercilessly removed by human beings for fuel, fodder, fencing and construction purposes.").

time.[14] The fusion of the three parameters—the three E's—prevents sustainable development from cascading back into the resourcism-environmentalism dichotomy, and ensures that social equity has equal footing with environmental and economic goals. The geographic scale dimension requires that sustainable development solutions span from local to global approaches with no "one size fits all" mentality. The time dimension forces sustainable development solutions to optimize in both the short-term (intragenerational) and long-term (intergenerational). As I demonstrate in Part II, each of these parameters and dimensions is firmly established in the sustainable development literature, albeit seldom in as tightly-knotted fashion as I contend they must exist. There is little for me or anyone else to add at this level, except further proselytizing.

If that defines sustainable development, it would not be anything remarkable. Indeed, die-hard resourcists and environmentalists attack sustainable development for failing to prescribe how to distribute environment, economy, and equity both spatially and temporally.[15] Sustainable development is not helpful if it offers no answer to that question. Thus far the response to such attacks has been to cast sustainable development as a "philosophy" and not a cookbook set of recipes.[16] But what is the philosophy, other than to describe all problems in terms of the three E's optimized over space and time? Here the literature has been sparse,[17] and it is to

14. At its broadest, sustainable development is the philosophy that today's progress must not come at tomorrow's expense, and that human progress thus must be sustained "not just in a few places for a few years, but for the entire planet into the distant future." Jonathan Lash, *Toward a Sustainable Future*, 12 NAT. RESOURCES & ENV'T 83, 83 (1997). For thorough bibliographies of sustainable development literature, see ENVIRONMENTAL ISSUES AND SUSTAINABLE FUTURES: A CRITICAL GUIDE TO RECENT BOOKS, REPORTS, AND PERIODICALS (Michael Marien ed., 1996); Keith Pezzoli, *Sustainable Development Literature: A Transdisciplinary Bibliography*, 40 J. ENVTL. PLAN. & MGMT. 575 (1997).

15. *See, e.g.*, Sanford E. Gaines, *Rethinking Environmental Protection, Competitiveness, and International Trade*, 1997 U. CHI. LEGAL F. 231, 231-32 (noting that after many international conventions on sustainable development, leaders are unable to agree "on more than a vague definition of the concept" and thus "the definition remains elusive"); John F. Potter, *Sustainable Development: Are We Being Conned?*, 17 ENVIRONMENTALIST 147, 147 (1997) ("[T]he glib and frequent use of the political phrase 'sustainable development' leaves most of us currently being conned.").

16. *See, e.g.*, Ruhl, *Thinking of Environmental Law*, *supra* note 1, at 993-95 (deflecting concerns that definitions of sustainable development are "open-ended and nonprescriptive" by comparing like concepts of democracy and justice that transcend "definitions").

17. Professor John Dernbach has gone as far as anyone to describe sustainable development in detail as a political philosophy or principle of governance. *See* John C. Dernbach, *Sustainable Development as a Framework for National Governance*, 49 CASE W. RES. L.

this question that I devote the main focus of the Article.

Part III of the Article describes sustainable development not simply as a philosophy, but as a non-static set of recipes, a problem-solving technique otherwise known as an algorithm. In formal mathematical terms an algorithm is a set of rules for solving a problem in a finite number of steps.[18] Less formally, but more broadly, algorithmic techniques are used by humans and human organizations in countless settings to solve complex, multi-variable, multi-dimensional, goal-optimization problems.[19] For sustainable development, algorithmic approaches mean that we will optimize all three parameters in both dimensions rather than maximize for any single parameter or dimension. Although this gives the appearance of muddling through life with mediocre performance in any given measure, the point is to maintain performance of the three E's over the long term and throughout our world.

Resourcism and environmentalism thrive on exactly the opposite approach—each maximizing a single parameter within a single dimension at the expense of the others—in order to deliver high short-term payoffs to their respective constituencies. Resourcists and environmentalists therefore typically reject sustainable development with its multi-dimensional, multi-parameter-optimizing approach to problem solving. Yet this is the ultimate strength of sustainable development, what truly makes it different from, and

REV. (forthcoming 1998) (manuscript on file with author). My focus here is on the problem-solving approach the political apparatus should use.

18. *See* PETER COVENEY & ROGER HIGHFIELD, FRONTIERS OF COMPLEXITY: THE SEARCH FOR ORDER IN A CHAOTIC WORLD 29 (1995) (describing "the formal definition of an algorithm as a recursive procedure for solving a given problem in a finite number of mechanical steps"); MURRAY GELL-MANN, THE QUARK AND THE JAGUAR 35 (1994) ("[T]he word 'algorithm' refers to a rule for calculating something."); STUART KAUFFMAN, AT HOME IN THE UNIVERSE 21 (1995) ("Algorithms are a set of procedures to generate the answer to a problem."); George Markowsky, *An Introduction to Algorithmic Information Theory*, COMPLEXITY, Mar.-Apr. 1997, at 14 (defining an algorithm as "a well-defined procedure for computing something").

19. Researchers increasingly turn to algorithm theory to improve our understanding of complex systems such as genetic evolution, *see* KAUFFMAN, *supra* note 18, at 245-47, and brain function, *see* COVENEY & HIGHFIELD, *supra* note 18, at 310. Some go so far as to suggest that algorithmic qualities underlie cultural and technological evolution. *See also* Stuart Kauffman & William Macready, *Technological Evolution and Adaptive Organizations*, COMPLEXITY, Vol. 1(2), at 26 (1995) (discussing technological evolution as an optimization problem); James N. Gardner, *Mastering Chaos at History's Frontier: The Geopolitics of Complexity*, COMPLEXITY, Nov.-Dec. 1997, at 28, 29 (discussing Kauffman's theories); Jonathan Haas, *A Brief Consideration of Cultural Evolution; Stages, Agents, and Tinkering*, COMPLEXITY, Jan.-Feb. 1998, at 12, 17-20 (discussing the concept of individual "tinkering" as an agent of cultural change).

superior to, the resourcism and environmentalism single-parameter models.

Part IV of the Article offers a preliminary outline of how sustainable development algorithms might be designed. We can confidently assume that sustainable development algorithms will be more complex than the one-step, one-dimension algorithms suggested by resourcism and environmentalism. Unfortunately, I cannot "write" sustainable development's multi-parameter, multi-dimension algorithm, and no one else has done so yet. Some of the recent literature on sustainable development hints at the algorithmic qualities I contend must be present in our approaches, and research in other fields, particularly geography,[20] offers tremendous advances in the uses of algorithms to "map" multi-dimensional optimization tasks. But the road ahead is long. Building on such foundations to develop robust algorithmic models of sustainable development will require a richness of data that simply does not yet exist. In addition, multi-variable, multi-dimension processes are mercilessly complex computationally. In short, all I can do for now is join others in encouraging a massive sustainable development research and modeling effort, to which I would add that the effort should build on complex systems algorithm theory as its theme.

II. THE MULTI-VARIABLE, MULTI-DIMENSIONAL APPROACH TO SUSTAINABLE DEVELOPMENT

The 1987 World Commission on the Environment and Development—better known as the "Brundtland Commission" after its chairperson—forged the classic statement of sustainable development. The Brundtland Commission defined the term as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[21] At the core of this concept is "a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet

20. *See infra* notes 97-101 and accompanying text.

21. WORLD COMM'N ON ENV'T & DEV., OUR COMMON FUTURE 43 (1987) [hereinafter OUR COMMON FUTURE]. For some background on this report and its importance to the origin of domestic sustainable development policy, see Donald A. Brown, *Thinking Globally and Acting Locally: The Emergence of Global Environmental Problems and the Critical Need to Develop Sustainable Development Programs at State and Local Levels in the United States*, 5 DICK. J. ENVTL. L. & POL'Y 175, 202-03 (1996).

human needs and aspirations."[22] This statement captures the three basic policy realms of sustainable development—economy, environment, and equity—and projects them over the present and future time scales. Recognizing that the parameters of economy, environment, and equity can be projected over different geographic scales as well, some literature on sustainable development also focuses the basic policies on global, national, regional, or local levels of analysis. The objective of sustainable development, in other words, is to achieve a social framework in which economy, environment, and equity all are sustainable in perpetuity over all geographic scales.

That is, to say the least, an audacious undertaking. Sustainable development advocates, however, have been steadfast in keeping the three E's fused together despite attempts by extreme resourcists and environmentalists to drag the policy toward opposite extremes,[23] and the sustainable development advocates appear to be winning.[24] Indeed, the initial report of the President's Commission on Sustainable Development (PCSD), *Sustainable America*, offers an example of sustainable development's firm and official description of the three E's, space, and time as co-equal policy partners.[25] A brief review of this and similar articulations of sus-

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22. OUR COMMON FUTURE, *supra* note 21, at 46.

23. *See, e.g.*, Bill Willers, *Sustainable Development: A New World Deception*, 8 CONSERVATION BIOLOGY 1146 (1994) (objecting to the economic component of the sustainable development message); J. William Futrell, *The Transition to Sustainable Development Law*, ENVTL. L. INST. RESEARCH BR. No. 3, Apr. 1994, at 5 ("[S]ome American environmentalists see the sustainable development movement as a threat undermining the environmental protection efforts of the last generation.").

24. *See* Gary D. Meyers & Simone C. Muller, *The Ethical Implications, Political Ramifications and Practical Limitations of Adopting Sustainable Development as National and International Policy*, 4 BUFF. ENVTL. L.J. 1, 3-15 (1996) (discussing the debate focusing on various proposed sustainable development definitions).

25. The PCSD issued its report in February 1997. *See* PRESIDENT'S COUNCIL ON SUSTAINABLE DEVELOPMENT, SUSTAINABLE AMERICA: A NEW CONSENSUS FOR PROSPERITY, OPPORTUNITY, AND A HEALTHY ENVIRONMENT FOR THE FUTURE (1996) [hereinafter SUSTAINABLE AMERICA]. President Clinton commissioned the PCSD by executive order on June 29, 1993 to "develop and recommend to the President a national sustainable development action strategy that will foster economic vitality." Exec. Order No. 12,852, 58 Fed. Reg. 35,841, 35,841 (1993). The PCSD has issued additional reports focusing on translating its recommended policies into concrete measures, *see* PRESIDENT'S COUNCIL ON SUSTAINABLE DEVELOPMENT, BUILDING ON CONSENSUS: A PROGRESS REPORT ON SUSTAINABLE AMERICA (1997), and has been authorized "to continue its work by continuing to forge consensus on policy, demonstrating implementation, getting the word out about sustainable development, and evaluating progress." 62 Fed. Reg. 45,283, 45,283 (1997). For further background and description of the PCSD's work and its place in the emerging domestic sustainable development policy, see Brown, *supra* note 21, at 202-03; John Dernbach et al., *U.S. Adherence to*

tainable development is necessary to appreciate why, if we are to achieve and maintain that policy framework, sustainable development must also be algorithmic in approach.

A. *The Three E's*

The PCSD summarized its report with a 16-point *"We Believe"* statement that completely abandons the resourcism-environmentalism dichotomy.[26] Central to this statement is the fusion of economy, environment, and equity into a policy triad. In its tenth point, for example, the PCSD prominently declared that "[e]conomic growth, environmental protection, and social equity are linked."[27] The PCSD repeated that theme in several different points of the "*We Believe*" statement,[28] as well as in the body of the report,[29] contending that one of the primary lessons learned from the last twenty-five years of environmental policy is that "[e]conomic, environmental, and social problems cannot be addressed in isolation."[30] After the PCSD report, in other words, there can be no doubt that sustainable development policy in the United States fuses economy, environment, and equity as three in-

Its Agenda 21 Commitments: A Five-Year Review, 27 ENVTL. L. REP. 10,504, 10,507-08 (1997); Lash, *supra* note 14, at 83-84 (PCSD co-chair); *see also* President's Council on Sustainable Dev., *President's Council on Sustainable Development* (visited Oct. 22, 1998) <http://www.whitehouse.gov/PCSD>. I use *Sustainable America* as the main vehicle for my summary of the five dimensions of sustainable development because it is the most widely accessible, coherently organized, and reader-friendly of any recent description of sustainable development doctrine. Notwithstanding that treaties relevant to sustainable development are more "official" than the PCSD report, I believe a strong case can be made that publication of *Sustainable America* is the most important event in the progression of sustainable development from policy idea to hard law for the United States. *See* J. B. Ruhl, *The Seven Degrees of Relevance: Why Should Real-World Environmental Attorneys Care Now About Sustainable Development Policy?*, 8 DUKE ENVTL. L. & POL'Y F. 273, 284-87 (1998).

26. SUSTAINABLE AMERICA, *supra* note 25, at vi (point 10).

27. *Id.*

28. *Id.* at v (point 2) (arguing that sustainable development will help "lead to the mutually reinforcing goals of economic growth, environmental protection, and social equity"); *id.* (point 3) (asserting that steady progress in reducing social disparities "is essential to economic growth, environmental health, and social justice"); *id.* (point 5) (arguing that economic growth is "essential for progress toward greater prosperity, equity, and environmental quality"); *id.* at vi (point 9) (declaring that local communities must increase their roles "in decisions about environment, equity, natural resources, and economic progress"); *id.* (point 16) (contending that citizens must have lifelong education "to understand the interdependence of economic prosperity, environmental quality, and social equity").

29. *See, e.g.*, *id.* at 12 (stating that the first three goals of the PCSD's work are to help secure health and the environment, economic prosperity, and equity); *id.* at 25 (noting that the essential components of sustainable development are "environmental health, economic prosperity, and social equity and well-being").

30. *Id.* at 26.

separable parameters. Numerous other policy statements and commentaries on sustainable development emphasize this fusion of the three E's into one policy.[31]

B. *Geographic Scale*

The PCSD's *"We Believe"* statement also recognizes the importance of geographic scale to sustainable development policy. Fundamentally, this means that national policy "must strengthen . . . communities and enhance their role in decisions about environment, equity, natural resources, and economic progress."[32] Similarly, the PCSD acknowledged the importance of national and international policy levels to achieving global sustainable development.[33] The PCSD report eloquently and succinctly demonstrates

31. *See* Dernbach et al., *supra* note 25, at 10,507 (arguing that sustainable development "requires us to see that there is virtually no such thing as a purely economic, environmental, or social problem"); John R. Nolon, *Fusing Economic and Environmental Policy: The Need for Framework Laws in the United States and Argentina*, 13 PACE ENVTL. L. REV. 685, 745 (1996) (asserting that sustainable development is "a framework for coordinating economic, environmental, and land use programs and guiding their gradual evolution into a coherent and efficient management system for the country's resources"); Susan L. Smith, *Ecologically Sustainable Development: Integrating Economics, Ecology, and Law*, 31 WILLAMETTE L. REV. 261, 263 (1995) ("Integrating economic and environmental concerns is the controlling policy objective of sustainable development.").

32. SUSTAINABLE AMERICA, *supra* note 25, at vi (point 9); *see also id.* at 83-107 (defining goals to strengthen local communities and economies).

33. *See id.* at 11-23 (defining national goals to encourage sustainable development); *id.* at 155-67 (defining the United States' role in international leadership to further sustainable development). International legal regimes are the focus of much of the literature on sustainable development. *See* Brian B.A. McAllister, *The United Nations Conference on Environment and Development: An Opportunity to Forge a New Unity In the Work of the World Bank Among Human Rights, the Environment, and Sustainable Development*, 16 HASTINGS INT'L & COMP. L. REV. 689 (1993); James T. McClymonds, *The Human Right to a Healthy Environment: An International Legal Perspective*, 37 N.Y.L. SCH. L. REV. 583 (1992); Mary Pat Williams Silveira, *International Legal Instruments and Sustainable Development: Principles, Requirements, and Restructuring*, 31 WILLAMETTE L. REV. 239 (1995); Edith Brown Weiss, *International Environmental Law: Contemporary Issues and the Emergence of a New World Order*, 81 GEO. L.J. 675 (1993). The United Nations channels its work on sustainable development through the Commission on Sustainable Development, which is serviced by the Department of Economic and Social Affairs' Division for Sustainable Development. Their work may be monitored through their web page, <http://www.un.org/esa/sustdev/csd.html>. In general, although many international law scholars are hopeful that the United Nations and other international regimes will contribute to the translation of sustainable development ideology into a practical body of law, most agree that at present "[t]he international legal system does not yet have the legal tools nor the institutional capacity to deal with the challenge." Susan H. Bragdon, *The Evolution and Future of the Law of Sustainable Development: Lessons from the Convention on Biological Diversity*, 8 GEO. INT'L ENVTL. L. REV. 423, 426 (1996). International policy on sustainable development, in other words, will depend largely on the commitment of individual nations toward common goals.

that sustainable development depends on explicit linkage of local, national, and global geographic scales and all their institutional, social, economic, environmental, and political features.[34] Consistent with that theme, an increasing amount of literature about sustainable development is devoted to translating the message to different scales of planning and impact.[35]

C. *Time*

The addition of intergenerational time scales to the sustainable development policy base is another critical topic of the PCSD report. Twice in its *"We Believe"* statement, the PCSD emphasizes the importance of integrating the needs of future generations in all policy decisions.[36] The future is linked to the present as well; thus, the PCSD's central vision statement calls for a "high quality of life for current and future generations."[37] As the PCSD concludes, "no one can predict the future—how people will live, or what exactly they will need—but it is possible to foresee the likely effects of some of today's decisions and to make choices that honor the interests of present and future generations."[38] This intra/intergenerational focus is found throughout sustainable development

34. SUSTAINABLE AMERICA, *supra* note 25, at 52-56 (discussing the need to build intergovernmental "place-based" partnerships); *see also* Ben Boer, *Institutionalising Ecologically Sustainable Development: The Roles of National, State, and Local Governments in Translating Grand Strategy Into Action,* 31 WILLAMETTE L. REV. 307 (1995).

35. *See, e.g.,* Simon Fairlie, *Sustainable and Low Impact Developments in the Countryside,* 1996 J. PLAN. L. 903 (discussing British national land use policy); Sergio Marchiso, *Mediterranean Sustainable Development in International Law,* 26 ENVTL. POL'Y & L. 260 (1996); Anne Buttimer, *Close to Home: Making Sustainability Work at the Local Level,* ENVIRONMENT, Apr. 1998, at 13 (case study of Ireland's south midlands region); Jon Chandler, *Regional Growth Means Achievable Growth,* NAT. RESOURCES L. INST. NEWS, Summer 1996, at 11 (discussing Portland city policies); James Longhurst et al., *Towards Sustainable Airport Development,* 16 THE ENVIRONMENTALIST 197 (1996) (applying sustainable development principles at the level of a single airport development); Monique Ross, *Sustainable Forest Management on Alberta's Private Woodlots; Defining a Role for Government,* RESOURCES, Fall 1996, at 1. Many sustainable development scholars believe that notwithstanding the global dimensions of many issues dealt with under the umbrella of sustainable development "in the United States in particular, state and local governments are an indispensable factor in achieving a sustainable future." Brown, *supra* note 21, at 203. At even smaller scales, the "ecology" of single industrial facilities has been identified as an important scale component of sustainable development. *See* Charles W. Powers & Marian R. Chertow, *Industrial Ecology: Overcoming Policy Fragmentation, in* THINKING ECOLOGICALLY 19, 19 (Daniel C. Esty & Marian R. Chertow eds., 1997).

36. Sustainable America, *supra* note 25, at v (point 2), vi (point 11).

37. *Id.* at iv.

38. *Id.* at 2.

literature.[39]

III. Sustainable Development as an Algorithm for Environmental Law

The challenge posed by the parameters and dimensions of sustainable development is twofold. First, each is in constant flux. Time is a moving target. The economy and the environment are dynamic systems in their own right.[40] Social equity varies not only with changes in economy and environment, but also with changes in social goals and perceptions.[41] Geographic scales change as technology makes the world subjectively smaller, and our understanding of the environment alters our conception of the reach of technology's effects.[42] It is not sufficient merely to strike a balance between economy, environment, and equity that brings the three into harmony for the moment; rather, we must continue to seek solutions to that three-way balance over time and through different geographies.

The second challenge of sustainable development is that it is often difficult to improve conditions in any one of its aspects without adversely affecting conditions in another. Even the short term, "win-win" outcomes in which economy, environment, and equity

39. *See* Paul A. Barresi, *Beyond Fairness to Future Generations: An Intragenerational Alternative to Intergenerational Equity in the International Environmental Arena*, 11 TUL. ENVTL. L.J. 59 (1997); Lothar Gundling, *What Obligation Does Our Generation Owe to the Next? An Approach to Global Environmental Responsibility: Our Responsibility to Future Generations*, 84 AM. J. INT'L L. 207 (1990); Edith Brown Weiss, *A Reply to Barresi's "Beyond Fairness to Future Generations,"* 11 TUL. ENVTL. L.J. 89 (1997); Edith Brown Weiss, *What Obligation Does Our Generation Owe to the Next? An Approach to Global Environmental Responsibility: Our Rights and Obligations to Future Generations for the Environment*, 84 AM. J. INT'L L. 198 (1990).

40. *See* Ruhl, *Thinking of Environmental Law*, *supra* note 1, at 953-67 (discussing research into the complex system qualities of the environment and economy).

41. The environmental justice movement, for example, did not exist as a relevant policy consideration before 1980, although environmental inequities certainly did. *See supra* note 3 and accompanying text.

42. Environmental problems seem increasingly to involve complex geographical relations. For example, researchers believe that migrating salmon accumulate pollutants in their body fat and then transport the pollutants from oceans to freshwater lakes and streams, where the pollutants are released when the salmon die and then decay after spawning. *See* J. Raloff, *Pollution Conundrum Has Fishy Solution*, 153 SCI. NEWS 293 (1998). Research is also underway to define the relationship between agricultural runoff in the Mississippi River basin and annual blooms of hypoxic conditions in the Gulf of Mexico, which are both increasing in terms of oxygen depletion and area affected. *See* David Malakoff, *Death By Suffocation in the Gulf of Mexico*, 281 SCI. 190 (1998); News Release from U.S. Dep't of Interior, U.S. Geological Survey, Nat'l Wetlands Research Ctr., Washington, D.C., *USGS National Wetlands Research Center to Host Workshop on Hypoxia in Gulf of Mexico*, (Feb. 18, 1998).

are all improved are difficult to achieve.[43] And even when local three-way "win" solutions can be achieved, doing so might adversely affect opportunities for improvements at different geographic scales, or for future generations.[44] In short, focusing on any one aspect of sustainable development can spell disaster for another.

Sustainable development thus requires more than adopting a policy *goal*; we also need to develop a policy *approach*. The approaches of resourcism and environmentalism are archaic in this sense: each strives for instantaneous maximization of their respective goals of resource use and environmental preservation. Such one-dimensional or one-parameter "victories" come at the price of sacrifices in other dimensions or parameters, and ultimately cannot last. The multi-parameter, multi-dimensional knot of sustainable development calls for a more sophisticated decisionmaking approach.

The policy approach that best responds to this feature of sustainable development is drawn from complexity theory—the field of research focusing on dynamic systems that are complex, adaptive, and evolutionary.[45] Two hallmark properties of such systems are their focus on multi-goal optimization outcomes, rather than single-goal maximization outcomes, and their algorithmic approach to adaptive, evolutionary decisionmaking. Both of these

43. Even core "green" programs, such as recycling, have their dark sides. *See* David Bacon, *Recycling—Not Always Green to its Neighbors*, NEIGHBORHOOD WORKS, May-June 1998, at 13 (discussing environmental problems, occurring mainly in low income areas, associated with recycling plants); *see also infra* note 62.

44. For example, many local growth management policies designed to improve three E conditions within a local planning boundary have been identified as contributing to social ills outside the planning area. *See* Timothy J. Choppin, *Breaking the Exclusionary Land Use Regulation Barrier: Policies to Promote Affordable Housing in the Suburbs*, 82 GEO. L.J. 2039, 2039-40 (1994); James A. Kushner, *Growth Management and the City*, 12 YALE L. & POL'Y REV. 68, 72-78 (1994).

45. Complexity theory refers to the body of literature and research devoted to "the study of the behavior of macroscopic collections of [interacting] units that are endowed with the potential to evolve in time." COVENEY & HIGHFIELD, *supra* note 18, at 7. Although the study of such systems can be quite theoretical, many of the recent and most influential works in the field focus on applications of the technical theory to real world phenomena, such as biological evolution. *See generally, e.g.*, JOHN L. CASTI, COMPLEXIFICATION: EXPLAINING THE PARADOXICAL WORLD (1994); JACK COHEN & IAN STEWART, THE COLLAPSE OF CHAOS (1994); GELL-MANN, *supra* note 18; BRIAN GOODWIN, HOW THE LEOPARD CHANGED ITS SPOTS: THE EVOLUTION OF COMPLEXITY (1996); JOHN HOLLAND, HIDDEN ORDER (1995); KAUFFMAN, *supra* note 18. For histories of the development of complexity theory, which has been brought about largely through the efforts of the Santa Fe Institute, see ROGER LEWIN, COMPLEXITY: LIFE AT THE EDGE OF CHAOS 8-22 (1992). *See also* JAMES GLEICK, CHAOS: MAKING A NEW SCIENCE 3-8 (1987) *and* M. MITCHELL WALDROP, COMPLEXITY (1992).

properties can and should be adopted as guiding principles for sustainable development policy.

A. *Multi-Goal Optimization vs. Single-Goal Maximization*

Complex systems are composed of a diversity of "parts" exhibiting an even more rich diversity of relationships. Complexity theory recognizes that within any complex adaptive system there are "conflicting constraints" among the different possible combinations of components' structural traits.[46] These constraints limit the degree to which any one trait can be "improved" without causing failure or degradation of another trait.[47] In considering how a system should be structured, therefore, one must evaluate the effects that changing one trait will have on the overall fitness of the system, by taking all other traits into consideration. A vision of complex systems emerges: a landscape of varying fitness level potentials for the system in a given environment with the peaks, valleys, and plains of the landscape representing the fitness potential of different combinations of system structures.[48]

We can construct such a fitness landscape for any system of connected interactions. The presence of such conflicting constraints in the system may make the fitness landscape flat or rugged and multipeaked. Much of the work in complex systems research is aimed at understanding systems' fitness landscape "search algorithms." These algorithms are the problem-solving computations and adaptations that systems apply in evolving across fitness landscapes; their objective is to stay in optimum positions at all times.[49]

46. *See* KAUFFMAN, *supra* note 18, at 169-73 (using a model of a genoic network to show that the more interconnected genes are, the more likely it is that conflicting constraints will exist).

47. The exoskeleton of an ant, for example, presents tremendous advantages at the ant's actual size, but if the ant were to increase in size, the disproportional weight of the exoskeleton would eventually kill the ant. *See id.* at 170. Indeed, research suggests that the balancing of constraints on body components is exactly how insects have evolved. *See* J. Travis, *Internal Fight Settles Size of Body Parts*, 153 SCI. NEWS 231 (1998). For an analysis of how conflicting constraints emerge from the diversity property of the legal system to form a fitness landscape for sociolegal evolution, see Ruhl, *Fitness of Law*, *supra* note 1, at 1448-56.

48. *See* KAUFFMAN, *supra* note 18, at 26.

49. Complex systems researchers view evolution in any system as "an attempt to solve a complex optimization problem." COVENEY & HIGHFIELD, *supra* note 18, at 118. The problem for adaptive systems is that, while the process of adaptation inherent to the "survival of the fittest" conception of evolution is designed to lead to ever-increasing improvements, all other systems in the picture competing for the same scarce resources are also adapting. Finding the optimal set of conditions thus becomes extremely difficult without robust algo-

When we map the interrelations and conflicting constraints of sustainable development's five components, we create such a fitness landscape. This landscape has peaks and valleys of overall sustainability performance fitness based on different combinations of the five components; our goal is to remain on optimally high ground as the landscape constantly evolves below our feet. Doing so requires that we design "search algorithms" to take into account the cross-dimensional conflicting constraints in ways that resourcism and environmentalism do not traditionally incorporate.

The prevailing schools of environmental policy have described our problem as a series of linear, one-dimensional decisionmaking systems. This approach assumes that economic conditions can be translated predictably into economic conclusions that call for prescribed economic measures, that environmental conditions can be translated predictably into environmental conclusions that call for environmental measures, and so on, as illustrated below in Figure 1.

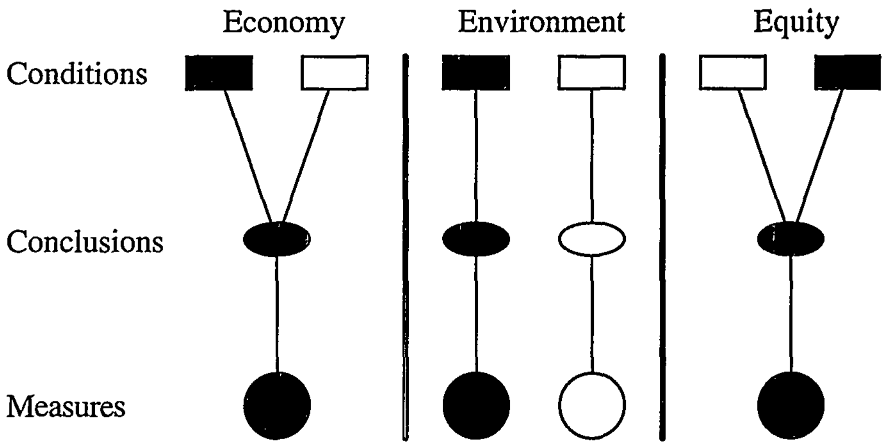

FIGURE 1. The approach taken in the prevailing environmental law model has been to depict environment, economy, and social equity as separate domains, each with its own set of relevant conditions, conclusions to be drawn from those conditions, and measures to apply in response to those conclusions. Under this model, there is no cross-over between the three domains, so that when any condition is turned "on" in one domain, represented by a darkened rectangle, only conclusions (ovals) and measures (circles) within that domain can be turned "on" as a result.

rithms designed to take into account competing systems' anticipated adaptations. *Id.* at 119-26, 247-59. The algorithm of a complex system, in other words, is its adaptation "program."

The linear, one dimensional approach works effectively when the links between condition, conclusion, and response are obvious and easily managed. When any condition is turned "on," the conclusions to be drawn are straightforward, the measures with which to respond to the condition are easy to adopt, and both exist principally in what is portrayed as the same domain as the condition. However, this model has proven ineffective in cases where there are cross-dimensional interactions. For example, responding to water pollution discharges from pipes is easy—follow the discharge up the pipe and regulate the discharger. However, responding to water pollution from agricultural and urban runoff has proven nearly intractable because of its complex cultural and economic causes and effects.[50]

Sustainable development thus requires that we work within the system of fully interrelated dimensions, in a manner illustrated by Figure 2.

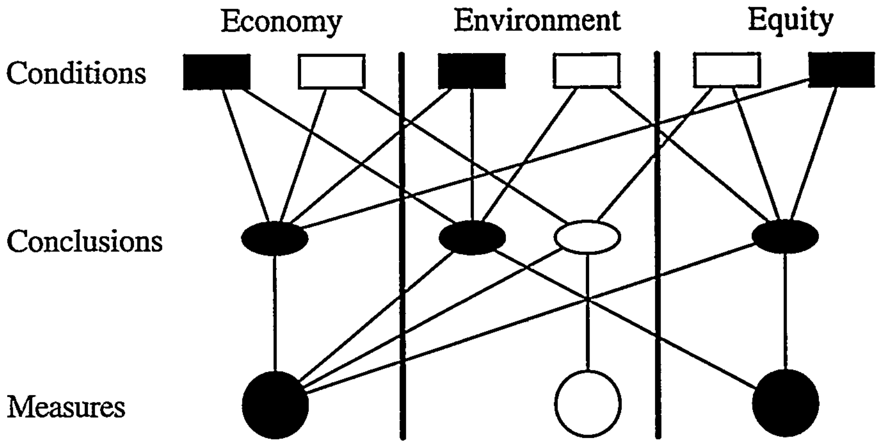

FIGURE 2. A more accurate model of the relationships between environment, economy, and equity shows their boundaries as permeable fields, allowing conditions in one domain to affect those in another. This allows a fuller vantage when addressing environmental problems. For example, if regional environmental degradation is principally the result of wealth and consumption disparities, then the solution to the problem may call for economic measures rather than direct environmental countermeasures.

Adding time and geographic scales to this conception provides a

50. *See* James M. McElfish Jr., *State Enforcement Authorities for Polluted Runoff*, 28 ENVTL. L. REP. 10,181 (1998); David Zaring, *Federal Legislative Solutions to Agricultural Nonpoint Source Pollution*, 26 ENVTL. L. REP. 10,128 (1996).

more accurate and complex description of the challenge. Conditions in one dimension may lead to conclusions in another dimension that may in turn lead to measures in yet another dimension. The first challenge of sustainable development is learning the inter-dimensional relations.

Unfortunately, current environmental laws with the most cross-dimensional focus have the least decisionmaking influence, whereas laws with the most narrow focus have the most influence.[51] Yet evidence that sustainable development is reversing this trend is emerging. For example, the PCSD's report on sustainable development unequivocally endorses this cross-dimensional focus. Two of its key *"We Believe"* points are that "[e]conomic growth . . . is essential for progress toward greater prosperity, equity, and environmental quality,"[52] and that "reducing disparities in education, opportunity, and environmental risk within society is essential to economic growth, environmental health, and social justice."[53] Indeed, throughout the fields of economics, ecology, and sociology, a new and rapidly expanding emphasis on interdisciplinary studies suggests that the policy triad of sustainable development is taking hold as a unifying theme for research and policy analysis.[54] Issues

51. For example, the National Environmental Policy Act (NEPA) arguably contains the broadest statement of purpose and scope of all environmental laws, proclaiming that "each person . . . has a responsibility to contribute to the preservation and enhancement of the environment" and that the federal government has the responsibility to "use all practicable means . . . [to] maintain, wherever possible, an environment which supports diversity and variety of individual choice." 42 U.S.C. § 4331(b)-(c) (1994). Yet it is well established that "NEPA itself does not mandate particular results, but simply prescribes the necessary process." Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 350 (1989). By contrast, the Endangered Species Act is arguably the most powerful substantive environmental law of all, having attained the status of public enemy number one in the eyes of property rights advocates, *see supra* note 10 and accompanying text, yet is hamstrung by the narrowness of its species-specific approach in comparison to our increasing awareness of the need for broader, ecosystem-level planning efforts. *See* Ruhl, *Thinking of Environmental Law, supra* note 1, at 968-75; *see also* SUSTAINABLE AMERICA, *supra* note 25, at 117-20 (endorsing ecosystem-level management of natural resources as a key sustainable development policy); David R. Hodas, *The Role of Law in Defining Sustainable Development: NEPA Reconsidered,* 3 WIDENER L. SYMP. J. 1, 6-8 (1988) (discussing the false sense of sustainability that NEPA compliance encourages); J. B. Ruhl, *Biodiversity Conservation and the Ever-Expanding Web of Federal Laws Regulating Nonfederal Lands: Time for Something Completely Different?,* 66 U. COLO. L. REV. 555, 579-601, 610-16 (1995) (comparing ESA and NEPA in this respect).

52. Sustainable America, *supra* note 25, at v (point 5).

53. *Id.* at v (point 3).

54. For example, many ecologists are advocating research into the economic value of the services different ecosystems provide to society, such as water filtration, pollination, and flood control. *See generally, e.g.,* NATURE'S SERVICES: SOCIETAL DEPENDENCE ON NATURAL ECOSYSTEMS (Gretchen C. Daily ed., 1997); Janet N. Abramovitz, *Putting a Value on Nature's "Free" Services,* WORLD WATCH, Jan.-Feb. 1998, at 10; Mari Jensen, *Ecologists Go to Town,* 153

such as population growth, consumption, and technology, which might previously have been studied discretely by these disciplines, are increasingly described as multi-factorial problems that can be adequately addressed only by adopting interdisciplinary approaches.[55]

SCI. NEWS 219 (1998); David Pimintel et al., *Economic and Environmental Benefits of Biodiversity*, 47 BIOSCIENCE 747 (1997). Likewise, many economists now advocate integration of environmental factors into any resource economics analysis. *See, e.g.*, A SURVEY OF ECOLOGICAL ECONOMICS (Rajaram Krishnan et al. eds., 1995); Graciela Chichilnisky & Geoffrey Heal, *Economic Returns from the Biosphere*, 391 NATURE 629 (1998). Greater understanding of social and cultural issues is also a part of the increased emphasis on interdisciplinary analysis of the environment. *See, e.g.*, Charles Victor Barber, *Forest Resource Scarcity and Social Conflict in Indonesia*, ENVIRONMENT, May 1997, at 4 (describing the link between socioeconomic decay and environmental degradation in Indonesia). Although pockets of interdisciplinary teams have existed for several years, the barriers between disciplines were substantially removed in early 1998 at a conference held in the Missouri Botanical Gardens on "Managing Human Dominated Ecosystems," where leading ecologists and economists gathered to share their models and theories of each other's worlds to find common ground. *See* J. B. Ruhl, *Valuing Nature's Services—The Future of Environmental Law?*, 13 NAT. RESOURCES & ENV'T 359 (1998) (summarizing various approaches in this respect). More broadly, several preeminent scientists have recently called for increased attention by scientists to social problems, principally those relating to environment. *See* Jane Lubchenco, *Entering the Century of the Environment: A New Social Contract for Science*, 279 SCI. 491 (1998); Edward O. Wilson, *Integrated Science and the Coming Century of the Environment*, 279 SCI. 2048 (1998). A concrete example of the effect of this new emphasis on interdisciplinary approaches is provided by the federal government's recent announcement of watershed rehabilitation research grants in which the grant agencies explained that "[t]he most competitive proposals will be those that include social scientists on the team and propose rigorous research in the social sciences." National Ctr. for Envtl. Research & Quality Assurance, EPA/NSF/USDA Partnership for Environmental Research, *1998 Water and Watersheds Research* (last modified June 22, 1998) <http://es.epa.gov/ncerqa/rfa/wshed.html>. Major research centers have followed the government's lead. *See generally* Gretchen Vogel, *An Institute for Planet Earth*, 280 SCI. 1182 (1998) (reporting that Columbia University has linked its earth sciences, biology, and social sciences faculties into one research institute).

55. Population, consumption, and technology are emerging as the three central focal points of interdisciplinary sustainable development studies. *See* THE CONSUMER SOCIETY 269-300, 333-66 (Neva R. Goodwin et al. eds., 1997); Jesse H. Ausubel, *Can Technology Spare the Earth?*, 84 AM. SCIENTIST 166, 177 (1996) (arguing that technology enables people to obtain goods and services more efficiently and that technology used wisely "can spare the earth"); James Salzman, *Sustainable Consumption and the Law*, 27 ENVTL. L. 1243 (1997). *See generally* JOEL E. COHEN, HOW MANY PEOPLE CAN THE EARTH SUPPORT? (1995). The three factors are inextricably linked in terms of both problem and solution. For example, where technological change causes environmental problems or is unresponsive as a solution to existing problems, consumption is a necessary focus of sustainable development policy. *See* Myers, *supra* note 11, 34-37; Reitze, *supra* note 11, 90-92. Although most fingers point at the United States for its high rate of consumption per capita, the inevitable marginal increases in consumption by huge numbers of poor people in countries with improving economies, assuming no improvement in technological efficiency, present a far more intractable problem for the future of sustainable development policy. *See* Myers, *supra* note 11, at 34; *see also* Vaclav Smil, *China Shoulders the Cost of Environmental Change*, ENV'T, July-Aug. 1997, at 6, 7-9, 33-36 (documenting the environmental costs of China's rapidly ex-

Notwithstanding the sheer giddiness with which this movement is hatching, sustainable development problems are much harder to solve than the "have your cake and eat it too" theme being promoted would suggest. The PCSD, for example, portrays economy, environment, and equity as always "mutually reinforcing goals"[56] and warns that "[s]eeing choices in terms of tradeoffs and balance reflects a history of confrontational politics."[57] To be sure, there are opportunities for mutual gains, as evidenced by the increasing focus of the business community, particularly of multinational companies, on sustainable development issues.[58] There is also

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panding economy). Given these trends, it is no surprise that the PCSD's *Sustainable America* report identifies population control as a key component of sustainable development policy. *See* SUSTAINABLE AMERICA, *supra* note 25, at 141-53. The intractability of that issue, however, suggests that the five dimensions of sustainable development must be optimized within a policy space that sets outer bounds on the possible approaches. For example, policies that rely on invasion of democratic institutions, or which threaten national security, would likely be rejected or resisted in North America and Europe even if they might result in a more sustainable global and national optimization. Such factors pose exogenous constraints on the optimization algorithm for sustainable development. *See supra* text accompanying notes 46-51.

56. SUSTAINABLE AMERICA, *supra* note 25, at v (point 2). Other leading policy statements of sustainable development project environment, economy, and equity as primarily mutually reinforcing components, downplaying their conflicting constraints. *See* Dernbach et al., *supra* note 25, at 10,507 (discussing Agenda 21).

57. SUSTAINABLE AMERICA, *supra* note 25, at 7.

58. *See, e.g.*, Stuart L. Hart, *Beyond Greening: Strategies for a Sustainable World*, HARV. BUS. REV., Jan.-Feb. 1997, at 66 (detailing a business professor's depiction of the market potential of sustainable development); Joan Magretta, *Growth Through Global Sustainability*, HARV. BUS. REV., Jan.-Feb. 1997, at 78 (discussing interview of Monsanto CEO Robert B. Shapiro, who projects sustainable development as an emerging business decision driver). Organizations that focus on the role of business in sustainable development include the World Business Council for Sustainable Development, *see generally* STEPHAN SCHMIDHEINY, CHANGING COURSE (1992) (outlining the business coalition's basic theme), and the World Resource Institute's Management Institute for Environment and Business. Even many strident environmentalists not normally aligned with "big business" interests are espousing the view that market dynamics and business profit motives may provide important foundations from which sustainable development policy can be infused into broader social agendas. *See, e.g.*, Paul Hawken, *Natural Capitalism*, MOTHER JONES, Mar./Apr. 1997, at 40. Examples include improved fertilizer management practices, *see* Pamela A. Matson et al., *Integration of Environmental, Agronomic, and Economic Aspects of Fertilizer Management*, 280 SCI. 112 (1998), and product "take back" programs in which consumers return spent products (e.g., worn out carpets) to manufacturers rather than to landfills, *see* Gary A. Davis et al., *Extended Product Responsibility: A Tool for a Sustainable Economy*, ENV'T, Sept. 1997, at 14-15. The PCSD's SUSTAINABLE AMERICA report advocates "take back" and similar programs designed to improve "industrial ecology" practices as important components of sustainable development policies. *See* SUSTAINABLE AMERICA, *supra* note 25, at 33-42. A recent survey of leading American business schools found that such business practices increasingly are covered in business school curricula and research. *See* World Resources Institute, *Grey Pinstripes with Green Ties: MBA Programs Where the Environment Matters* (last visited Oct. 26, 1998) <http://www.wri.org/wri/meb/mba-home.htm>.

strong evidence that environmental protection is less likely when regional economic conditions are substandard, so that initial surges of economic growth in developing nations may go hand in hand with increased environmental protection.[59]

The reality of multi-factorial optimization problems, however, is that they inevitably experience conflicting constraints. Countless examples already exist in which what was originally perceived as a win-win solution turned out to present a far more complicated set of wins and losses across the three E's, geography, and time.[60] The problem is that the sustainable development movement wants to be able to offer only home runs, but in swinging only for home runs it risks too many strike-outs. Multi-factor optimization requires instead that we are able to hit the ball all over the field and adapt to any pitcher's slew of weapons—that we focus on learning the inherent conflicting constraints in the sustainable development system, which pose what complex-systems researchers call "hard combinatorial optimization problems,"[61] and accept that we will have to live with less than perfect solutions.[62] Any adjustment of one system component in a tightly interconnected system causes every other component to "adjust," which in turn causes every

59. This phenomenon is known as the "environmental Kuznets curve," and the complete story is that the positive reinforcing relationship eventually reverses as income continues to rise. *See* F.G. Hank Hilton, *Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions*, 35 J. ENVTL. ECON. & MGMT. 126 (1998).

60. For example, the "Blue Revolution" that has brought economic prosperity for some in southeast Asian countries through shrimp aquaculture supposedly also relieved pressures on take of wild shrimp. But shrimp aquaculture has generated its own set of environmental problems, including depletion of mangrove wetlands to make room for shrimp ponds and, ironically, depletion of wild shrimp due to the practice of stocking ponds with young shrimp captured en masse from the wild, many of which die before harvest. *See* Claude E. Boyd & Jason W. Clay, *Shrimp Aquaculture and the Environment*, SCI. AM., June 1998, at 56.

61. *See* KAUFFMAN, *supra* note 18, at 248-51; Kauffman & Macready, *supra* note 19, at 42; William G. Macready & David H. Wolpert, *What Makes An Optimization Problem Hard?*, COMPLEXITY, Vol. 1(5), 1995-1996, at 40. In other words, some system optimization problems are so hard that running the search algorithm takes longer than the time the system takes to run its course. This "hardness" level of an optimization problem is described as its "algorithmic information complexity," referring to the size of the smallest algorithm that computes the problem or a complete description of it. *See* COVENEY & HIGHFIELD, *supra* note 18, at 34-39, 423; GELL-MANN, *supra* note 18, at 37-41, 48-66.

62. This is the logical conclusion from the concept of problem "hardness," or algorithmic information complexity. In other words, as an optimization problem becomes harder, looking for the perfect solution eventually becomes too costly in terms of time and energy. A better approach is to develop algorithms that search for good to excellent solutions and adapt to changing conditions so as to keep the system in that zone of outcomes over the long run. *See* KAUFFMAN, *supra* note 18, at 249.

other component to adjust again, and so on. All the components are locked in perpetual coevolution, with the relationships leading to positive and negative feedback loops. Thus, the relationship between the three E's is not one of complete positive synergy, but rather a complex, coevolving web of positive and negative interactions, as illustrated below in Figure 3.

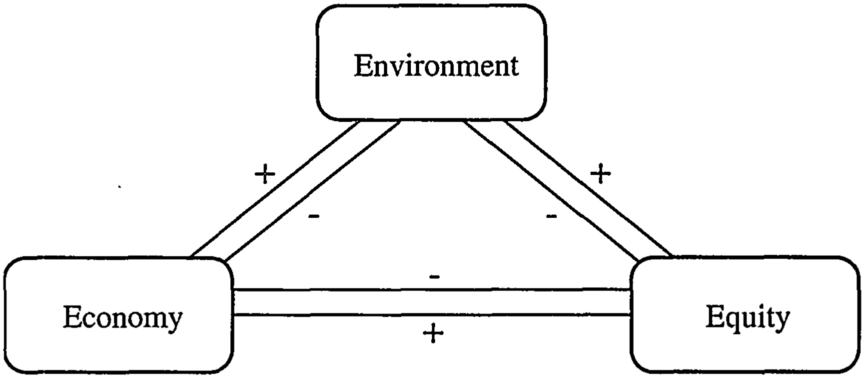

FIGURE 3. Almost any decision concerning the environment, economy, or equity has both positive and negative effects on the other two domains. A three-way "win" solution, in which a positive adjustment in one field leads directly and exclusively to positive adjustments in both other fields, is likely to be rare. However, sustainable development advocates may actually put all three fields in peril if they promise, and then seek, only such outcomes.

Of course, this three-way relationship leaves out time and space, both of which must be integrated into the optimization balance. For example, an "improvement" in economic performance (e.g., increased employment) in Time 1 at Location A could lead to equity improvements (e.g., closing wealth disparity) at Time 2 at Location A. The increased consumption that would follow, however, could lead to environmental degradation (e.g., fishery depletion) at Time 3 and Location B, leading eventually to decreased economic performance (e.g., higher prices) at many locations at Time 4.

When geographic scale is added to this already complex web, therefore, the level of interaction among every local, regional, and national optimization solution becomes evident as shown in Figure 4.

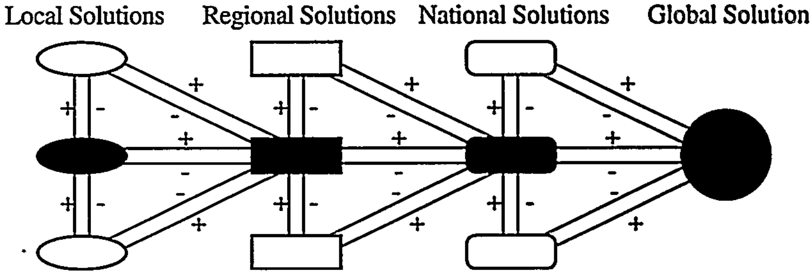

FIGURE 4. Optimization solutions at any given scale necessarily affect available solutions at other locations of the same scale, as well as at locations elsewhere in the hierarchy of geographic scales. Those effects will likely involve a blend of direct and indirect positive opportunities and negative constraints of different magnitudes. Thus, a solution reached at a particular regional location will positively and negatively affect—and be affected by—solutions at every other location in every other scale. However, these interactions do not play out even as simply as is indicated by Figure 4. A local solution in one location may have a strong effect on the solution of a different region or nation; it is not necessarily the case that the strongest interactions will take place straight up and down the hierarchy. But depicting the true level of complexity would be hopelessly messy, even using only three locations at each scale.

Any optimization solution at one point in time also necessarily moves option boundaries and payoff outcomes for other times, as described by Figure 5.

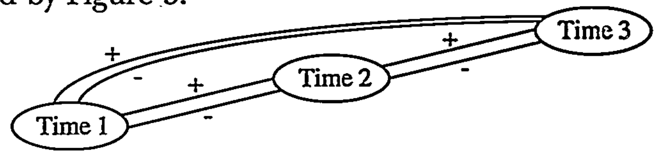

FIGURE 5. Using whatever time horizon adopted as the planning increment, an optimization solution in one period necessarily affects options in other periods. Planning only for the present affects future possibilities; planning only for the future affects present possibilities; and past events affect both the present and the future. Sustainable development requires optimization among all planning periods—in perpetuity.

Traditional economic, environmental, and social policies do not typically depend on or facilitate planning based on this reality, and thus are ill-equipped to reach optimization solutions across more than one of the five dimensions. Some of the more recent innovative solutions to combine environmental, economic, and equity problems suggest that decisionmakers can escape the trap of past practices and find ways of integrating not only the three E's, but also time and space. These innovative solutions may achieve outcomes that grab headlines because of their seemingly unusual view of the world.[63] In order to accept the conflicting constraints of sustainable development's complexity as an inherent premise—and I believe we must if sustainable development is to succeed—then a new way of thinking about how to set goals, work toward them, and measure success is needed. Adaptive system decisionmaking provides one potential way for meeting this need.

B. *Adaptive Management vs. Prescriptive Management*

Sustainable development, like other complex decisionmaking systems, has no beginning or end points. It is a continuous process. The essence of such systems is "not described by their beginnings, their short-run appearances, their alleged purposes, or their poorly predicted destinations, but by their algorithms."[64] In other words, it is the decisionmaking "program" that defines the long-term success of systems. Optimization across a fitness landscape involves using optimizing search algorithms not only to control for direction, but also to test the fitness of different system component combinations and adapt to the results continuously.[65] The system's optimization algorithm must be adaptive, moreover, because the systems with which it interacts are evolving in their own searches for the most fit solutions.[66] A decisionmaking system that simply searches for the solution that appears best at the moment and prescribes it for the long term, without the opportunity for reexamination, is likely to fail over time. Complex, adaptive, evolutionary systems incorporate algorithmic decisionmaking tools that allow

63. A classic example of innovation in sustainable development is New York City's program to secure long term drinking water quality principally through acquisition and management of the distant watersheds that supply the city's water rather than through more costly water treatment facility improvements at the point of delivery. *See generally* Michael C. Finnegan, *New York City's Watershed Agreement: A Lesson in Sharing Responsibility*, 14 PACE ENVTL. L. REV. 577 (1997) (providing an overview of circumstances of the agreement from the perspective of a principal negotiator for the state). Recently the City of Austin, Texas, took a similar approach, approving $65 million in bonds to acquire undeveloped land in a watershed that contributes to the city's recreational and drinking water sources. *See* Chuck Lindell, *City Reveals Proposition 2 Land List*, AUSTIN AM.-STATESMAN, Apr. 29, 1998, at A1.

64. Lewis Smith, *The Search for a Taxonomy of Dynamic Systems*, COMPLEXITY, Dec. 1997, at 7.

65. *See* Macready & Wolpert, *supra* note 61, at 40 ("To solve optimization problems effective algorithms must be constructed . . . .").

66. Kauffman's description of a "coupled fitness landscape" offers the most elegant theory of such coevolving system fitness landscapes. *See* KAUFFMAN, *supra* note 18, at 215-35.

adaptive long-term fitness optimization through repeated reevaluation of system design.[67]

Sustainable development literature is moving toward this adaptive optimization algorithm approach. For example, the PCSD report recognizes that "change is inevitable"[68] and that "[w]e need a new collaborative decision process that leads to better decisions [and] more rapid change."[69] Adaptive management's strongest champion in environmental policy circles is Kai Lee, who defines it as applying "the concept of experimentation to the design and implementation of natural resource and environmental policies."[70] Lee's objectives are similar to the goals of complex system algorithm theory: to open the decisionmaking process up to continuous change based on a continuous input of information and analysis.[71] Because the behavior of environmental and human systems is unclear, it is not always initially clear how to reach the goal of sustainable development.[72] Failure to experiment, in other words, would be folly. Lee's early work, applying this approach to the Columbia River ecosystem in Oregon and Washington, has led other commentators to propose an even broader agenda of adaptive management in environmental policy.[73] This suggestion is beginning to take hold in concrete policy proposals[74] and

67. Kauffman and Macready pull the concepts of optimization and adaptation together as follows:

> Adaptive organizations need to develop flexible internal structures that optimize learning. That flexibility can be achieved in part by structures, internal boundaries, and incentives that allow some of the constraints to be ignored some of the time. Properly done, such flexibility may help organizations achieve higher peaks on fixed landscapes and optimize tracking on a deforming landscape. A general approach to adaptation as coevolutionary problem solving within the organization merits serious attention.

Kauffman & Macready, *supra* note 19, at 43.

68. Sustainable America, *supra* note 25, at v (point 2).

69. *Id.* at vi (point 8). The PCSD also endorsed performance-based measurements of environmental protection as a key sustainable development policy. *Id.* at 34.

70. KAI LEE, COMPASS AND GYROSCOPE 53 (1993).

71. *See* George Frampton, *Ecosystem Management in the Clinton Administration*, 7 DUKE ENVTL. L. & POL'Y F. 39, 45 (1996) (commenting that adaptive management calls for continuous revision and adjustment of plans as conditions change).

72. *See* LEE, *supra* note 70, at 8 (asserting that, in order to achieve an environmentally sustainable economy, we must first learn to understand the relationship between humans and nature and the relationships among people).

73. *See* Alastair Iles, *Adaptive Management: Making Environmental Law and Policy More Dynamic, Experimentalist, and Learning*, 10 ENVTL. & PLAN. L.J. 288 (1996).

74. *See* Robert Costanza et al., *Principles for Sustainable Governance of the Oceans*, 281 SCI. 198 (1998) (advocating adaptive management as one of six principles required for sustainable oceans policy); THE KEYSTONE CTR., THE KEYSTONE NATIONAL POLICY DIALOGUE ON

government programs.[75]

IV. THE LONG ROAD AHEAD: DESIGNING ALGORITHMS THAT WORK FOR SUSTAINABLE DEVELOPMENT

Transporting models of complex adaptive systems derived from physical systems to social organizations is a tall order. Stuart Kauffman, however, is confident that this can be done,[76] and others have followed his lead with vigor.[77] The movement does have its critics. But I would ask them to consider these fundamental aspects of sustainable development and how closely they correspond to complex systems theory:

1. Sustainable development places environment, economy, and equity on equal footing as policy goals that must be harmonized.

2. Sustainable development demands that the harmonization of environment, economy, and equity be consistently maintained over geographic and time scales.

3. Environment, economy, and equity cannot be always mutually reinforcing over all geographic and time scales. Conflicting constraints exist.

4. Complex direct and indirect positive and negative feedback loops thus exist between environment, economy, and eq-

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ECOSYSTEM MANAGEMENT 15-21 (1996) (advocating adaptive management techniques as the framework for ecosystem management).

75. *See* Frampton, *supra* note 71, at 45-46 (discussing use of adaptive management methods in endangered species protection programs); U.S. FISH & WILDLIFE SERV., U.S. DEP'T OF COMMERCE, ENDANGERED SPECIES HABITAT CONSERVATION PLANNING HANDBOOK 3-24 to 3-26 (1996) (advocating the use of adaptive management techniques in permitting under the Endangered Species Act).

76. *See* KAUFFMAN, *supra* note 18, at 245-304 (applying the theory to politics, business, technology, and almost everything else).

77. *See generally, e.g.*, CHAOS, COMPLEXITY, AND SOCIOLOGY: MYTHS, MODELS, AND THEORIES (Raymond A. Eve et al. eds., 1997) (collection of articles applying complex systems theory to various social and political science topics); Symposium, *Complexity and Business*, COMPLEXITY, Mar.-Apr. 1998, at 21 (collection of articles examining the application of complex systems theory to business organizations and markets). One of the difficulties of trying to apply complex systems theories derived from physical systems to human organizational systems is that, whereas dripping faucets and evolving insects do not "plan" their system behavior, humans attempt to do so, and do so with normative goals in mind. *See* Ruhl, *Fitness of Law*, *supra* note 1, at 1450-51. The optimization of sustainable development thus poses normative issues, such as how much government control is desired, how much intervention in individual family planning decisions will be tolerated, how much income disparity is acceptable, and so on. The point of the algorithmic approach is to allow those normative decisions to be as fully informed as possible in terms of the effect of different choices on the overall performance of the system.

uity, particularly when projected across large geographic and time scales.

These features capture the essence of the "hard combinatorial optimization problems" that are the bread and butter of complex systems research. In other words, sustainable development means trying to keep numerous complicated, conflicting, and overlapping environmental, economic, and equity needs and goals viable for many people, across enormous landscape scales, forever.

I have focused on the core problem-solving technique of complex systems—the adaptive search algorithm—as a theme for sustainable development. What would such a search algorithm look like for sustainable development? Unfortunately, our current knowledge base cannot predict what its shape will be, but we can explore the options by contrasting the basic decisionmaking models of resourcism and/or environmentalism with models of sustainable development. The resourcism versus environmentalism debate places questions in one-step, one-dimensional algorithms. For example, resourcism's algorithm is simple: Is it good for the economy today? If yes, do it; if no, don't do it. Replace *economy* with *environment* and you have environmentalism's algorithm.[78] By contrast, a crude algorithm for sustainable development would (1) find the optimum for all three E's at one location and time, taking into account the effects tinkering with any one will have on the other two; then (2) evaluate the effects of the local solution on all other local, regional, and global solutions; then (3) evaluate the effects of the local solution on all future solutions; and finally (4) repeat the process until the system reaches a stable, sustainable equilibrium. The sustainable development algorithm thus must iteratively solve the basic three E's goals, projected across time and space, by accounting for all the feedback and feedforward loops that exist in their coevolving system. This is a hard combinatorial problem if ever there was one.

Despite the theoretical advancements in algorithm theory of the last decade, most complex systems researchers concede that problems of this magnitude remain beyond our grasp. To be sure, law has attempted to tackle hard combinatorial problems many times before.[79] However, as in the physical and biological sciences, law and other social sciences will require "a confluence of al-

78. Likewise, replace *environment* with *equity* and you have the algorithm for environmental justice advocates.

79. For a broad discussion of how hard combinatorial problems pose complications

gorithm development and empirical data" to crack the problem.[80] Indeed, to build formal theorems about observable natural and social systems on this scale, we will need vast new sources and analyses of information about the factors relevant to sustainable development, and we will need new modeling tools for tackling the hard combinatorial problems that they pose. Fortunately, albeit without overt references to algorithm theory, researchers in fields relevant to sustainable development have begun work on these two essential tasks.

A. *Information*

Adaptive systems require extensive, reliable information, and sustainable development systems will be no exception. Economic systems researchers are able to access mountains of data every day with which to make short- and long-range adaptive decisions. Social and demographic statistics are also abundant. However, we lack adequate databases regarding the environment that will allow us to maintain information concerning the relationships among the environment, the economy, and social equity. Sustainable development will not work as a process until these information gaps are filled.

The challenge in this regard goes deeper than simply collecting reams of information; rather, we must decide what information is relevant. For several years, national and international organizations have been searching for the right "indicators" of sustainable development.[81] But to the extent these indicators reflect discrete

in many fields of law, see Eric Kades, *The Laws of Complexity and the Complexity of Laws: The Implications of Computational Complexity Theory for the Law*, 49 RUTGERS L. REV. 403 (1997).

80. Coveney & Highfield, *supra* note 18, at 310.

81. The PCSD recognizes that we must identify indicators of national environmental, economic, and equity progress. SUSTAINABLE AMERICA, *supra* note 25, at 14-16. The PCSD devotes several pages of the report to the topic of information, noting that present databases are not always in a form useful to sustainable development decisionmaking and that the relations between environment, economy, and equity are an important but largely unaddressed topic of research. *Id.* at 58-69; *see also* U.S. Interagency Working Group on Sustainable Development Indicators, *Sustainable Development in the United States: An Experimental Set of Indicators* (visited Nov. 14, 1998) <http://198.183.146.250/>. This effort is also the focus of the United Nations' Commission on Sustainable Development, which has been working toward developing a set of indicators of sustainable development for all countries to use by the year 2000. *See* United Nations, Department of Economic and Social Affairs, *Indicators of Sustainable Development* (visited Oct. 23, 1998) <http://www.un.org/esa/sustdev/isd.htm>; *see also* ALLEN HAMMOND ET AL., WORLD RESOURCES INSTITUTE, ENVIRONMENTAL INDICATORS: A SYSTEMATIC APPROACH TO MEASURING AND REPORTING ON ENVIRONMENTAL POLICY PERFORMANCE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT (1995);

sets of environmental, economic, and social data, multi-factorial decisions will remain difficult. An emerging trend has been to identify interdisciplinary indicators that focus on more than one domain at once. For example, efforts to develop a discipline of environmental economics have produced data and indicators more relevant to sustainable development's five-dimensionality.[82]

Evidence that this has become the primary mission of this nation's scientific community is supported by the June 1998 report of the President's Committee of Advisors for Science and Technology ("PCAST"), *Teaming With Life*.[83] The PCAST recognizes that in order "to optimize the union between the environment and the economy" we need "an extensive and frequently updated environmental knowledge base."[84] One of its key recommendations is that "[s]teps should be taken to focus interdisciplinary economic, sociological, and ecological research on the relationship between the market economy and natural capital, between society and the biosphere."[85] The objective of such research, the PCAST proclaims, must be to encourage a sustainable relationship between the economy and the environment.[86] The PCAST's recommendations in that regard must be aggressively implemented for sustainable development to be a viable goal.

B. *Models*

Data without theory are just data. A surplus of information about the environment, economy, equity, space, and time will do little good if we lack a model to interpret the data. Unfortunately, one fault of the political bandwagon carrying sustainable development forward is that it has failed to develop either a robust sustainable development model or a plan for implementing such a model. As the PCAST recognizes in *Teaming with Life*, "increasingly sophis-

International Institute for Sustainable Development, *Compendium of Sustainable Development Indicator Initiatives and Publications* (visited Oct. 22, 1998) <http://iisd1.iisd.ca/measure/compendium.asp>.

82. *See supra* note 56 and accompanying text. For a discussion of how the results of these research efforts can be translated into legal doctrine, see James Salzman, *Valuing Ecosystem Services*, 24 ECOLOGY L.Q. 887 (1997).

83. *See* President's Committee of Advisers on Science and Technology, Panel on Biodiversity and Ecosystems, *Teaming with Life: Investing in Science to Understand and Use America's Living Capital* (last modified March 1998) <http://www.whitehouse.gov/WH/EOP/OSTP/Environment/html/teamingcover.html> [hereinafter *Teaming with Life*].

84. *Teaming with Life*, *supra* note 83 (Executive Summary).

85. *Id.*

86. *Id.* (§ III).

ticated modeling paradigms and algorithms will be important tools, not only for the conduct of the theoretical research to understand our living resources, but also for translating the research results into helpful and useable tools for ecosystem management."[87] Recently, several promising approaches have emerged in this area.

For example, Gilberto C. Gallopin and Paul Raskin of the Stockholm Environment Institute use multinational business planning practices as inspiration for developing scenarios of global sustainability.[88] They point to the uncertainty inherent in quantitative sustainable development predictions, a result of "our limited understanding of human and ecological systems and the inherent indeterminism of complex dynamic systems," and recommend the more qualitative exercise of scenario building.[89] Using terms familiar to complex systems research, scenario practitioners describe the process as a logical narrative designed to deal with potentially far-reaching changes. They use insights gained from quantitative analysis to describe the current state of a given system, the driving forces of change, and the attracting and repelling forces that will respond to that change.[90] By playing out different realistic combinations of those factors before panels of experts in the relevant fields, qualitatively different futures can be modeled.

These scenarios allow Gallopin and Raskin to ask how different institutional and value frameworks would affect and be affected by population, economy, environment, equity, technology, and conflict over the short- and long-runs.[91] Their "ecocommunalism" scenario, for example, assumes a deep green political structure of local, face-to-face democracy, small technology, and economic autonomy, which their scenario predicts will result in sharply reduced population and economy, vastly improved environment and technology, and cyclical equity and conflict.[92] Although these scenarios rely on quantitative support for their qualitative descriptions

87. *Id.* (§ II).

88. *See generally* Gilberto C. Gallopin & Paul Raskin, *Windows on the Future: Global Scenarios & Sustainability*, ENV'T, Apr. 1998, at 7. Scenarios have long been used by military planners and corporate strategists as a means of narratively playing out different possible futures based on adjustments to key variable assumptions—a form of "future history" writing. *See* ALLEN HAMMOND, WHICH WORLD?: SCENARIOS FOR THE 21ST CENTURY: GLOBAL DEFINITIONS, REGIONAL CHOICES 14-16 (1998).

89. Gallopin & Raskin, *supra* note 88, at 7-8.

90. *See id.*

91. *See id.* at 9-10.

92. *See id.* at 9; *see also* HAMMOND, *supra* note 88, at 87-101 (chapter developing different scenarios based on critical environmental trends); Bryan G. Norton, *Locating Sus-*

and predictions, their "big picture" approach may prove more useful for large-scale policy decisions than for on-the-ground decisionmaking, particularly at local and regional levels.

A more active and dynamic modeling approach is offered by Anthony Clayton and Nicholas Radcliff of the Institute for Policy Analysis and Development. Clayton and Radcliff use "positional analysis" to generate "sustainability assessment maps."[93] Their approach, steeped in complex adaptive systems doctrine,[94] leads them to the conclusion that sustainable development modeling at any scale requires "an open-ended approach . . . where the outcome is not seen as being an optimal solution to a particular problem, but a continuous learning process."[95] To assist in that continuum of multi-factorial decisionmaking, a project, policy, or other decision can be displayed on a diagram in which each of the important dimensions for decisionmaking is represented on an axis on which measurements of change or indications of priority are mapped. Explicit conclusions about the feedback between factors are assigned to the process. Then, as with Gallopin and Ruskin's scenarios, different value profiles (placing an emphasis on economy or equity, for instance) are used to play out how the interacting system of factors behaves over time.[96]

Ultimately, scenario building and positional analysis remain very crude ways of modeling sustainable development. They rely heavily on judgment, expertise, and rough approximation, and less on methodical algorithms. As more information pertinent to sustainable development decisionmaking becomes available, for instance through PCAST, scenarios and positional analysis will either become increasingly crude or more time-consuming to develop. We should therefore begin now to develop more sophisticated computer-based modeling techniques, so that we can obtain and compile the data in the correct format, with the modeling technique in mind, and process it more immediately and reliably.

As the PCAST has recognized, the most promising modeling tool for such purposes is known as Geographic Information Sys-

tainability, 280 SCI. 1710 (1998) (discussing how scenarios will help develop sustainable development optimization).

93. *See* ANTHONY M.H. CLAYTON & NICHOLAS J. RADCLIFF, SUSTAINABILITY: A SYSTEMS APPROACH 195-207 (1996).

94. *See id.* at 28-48.

95. *Id.* at 187.

96. *See id.* at 185-207.

tems ("GIS").[97] Defined formally as "a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth,"[98] GIS is not limited to working within the traditional cartographic discipline of geography. Rather, its ability to work with "surfaces" and "vectors" of any variable or set of variables that has a geographic or other dimensional component,[99] could prove useful not only as a way of displaying the same sustainable development factors that might be discussed in a scenario or positional analysis, but also as a tool for more efficiently and reliably modeling those factors. GIS also provides an immediate view of how the manipulation of specific factors affects the overall system. As with any computer software, however, GIS is only as good as the algorithms it uses to do its work, and thus using GIS will require that we explicitly develop reliable algorithms for sustainable development analysis rather than depend exclusively on expert judgments about the future.[100]

The PCAST has called for a "next generation" National Biological Information Infrastructure to create a "fully digitally accessible, distributed, interactive research library system," and for GIS-based and similar modeling tools that can "efficiently search through terabytes of . . . biodiversity and ecosystems datasets, make correlations among data from disparate sources, compile those data in new ways, analyze and synthesize them, and present the resulting information in an understandable and useable manner."[101] In essence, we need to bring the environmental side of information and modeling up to the level already achieved for economic and social data, and then move to the next level in which multi-factor information can be generated and modeled. Until that vision is

97. *See Teaming with Life, supra* note 83 (§ II); Nolon, *supra* note 31, at 739 ("[GIS] provides a feasible and cost-effective means of collecting and distributing a wide range of information relevant to environmental pollution, protection and territorial planning.").

98. NICHOLAS CHRISMAN, EXPLORING GEOGRAPHIC INFORMATION SYSTEMS 5 (1997).

99. *See id.* at 157-83 (discussing rates of carbon emissions, income levels, and rates of carbon emissions correlated with income levels).

100. *See, e.g.*, Stuart Pimm & John H. Lawton, *Planning for Biodiversity*, 279 SCI. 2068 (1998) (discussing the importance of GIS algorithms in the discipline of biogeography, using the example of studies correlating land values and endangered species locations).

101. *Teaming with Life, supra* note 83 (§ IV). For an example of the use of GIS toward this goal, see I.D. Cresswell & R. Thackway, *Mapping a Great Big Sea*, GLOBAL BIODIVERSITY, Summer 1998, at 2-9, which discusses Australia's project of mapping its marine environment in GIS format to assist in biodiversity management.

achieved, sustainable development will remain a policy that is difficult to know how to practice.

V. Conclusion

The chief criticism of sustainable development has been that it is undefined and amorphous because it fails to prescribe concrete standards, criteria, and measures with which to shape society's relationship to the environment. The current environmental legal system, by contrast, spawns industry-specific emission limits and similar prescribed standards, such as those found in the Code of Federal Regulations, that are designed to be applied without much further judgment. Until sustainable development provides a framework to deliver that level of detail, the argument goes, it will not be a useful policy tool.

But this argument misses the point entirely. Sustainable development will never produce that type of detailed, relatively static framework, because the multi-parameter, multi-dimensional nature of sustainable development knots the concept together in a constantly evolving system aimed at maintaining optimized fitness over the long term. No optimization solution worked out today could ensure sustainable development for the future, at least not for very long.

Because traditional environmental law has not been designed with policy adaptation and evolution in mind, change in environmental law has been a tumultuous, oft-reviled process. What is new and important about sustainable development, therefore, is that it does not repeat this error of the past. Sustainable development provides a framework for sustainable evolution *of law.* Indeed, as sustainable development fuses environment, economy, and equity into one policy realm, eventually the term *environmental* law will become an anachronism.

I have found complexity theory useful for describing how the framework for the evolution of law must be built: it must be designed around adaptive optimization algorithms. Sustainable development must forge such algorithms and the ability to use them. At a more functional level, the ways in which the five parameters and dimensions of sustainable development interrelate and coevolve over time must be described. Interdisciplinary research efforts will be an important starting point.

There is much work to be done to improve the current, crude algorithms of sustainable development. The goal of adaptive optimization is of primary importance to that task. To accomplish it, we must resist being dragged back into the resourcism-environmentalism dichotomy that has dominated the last three decades of environmental policy. The work ahead will thus be challenging, but it also may be the most rewarding ever to have been offered—it may mean our survival.