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# 1 An introduction to methods and applications in environmental studies

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The prosperity and fate of humanity are intricately tied to the biophysical and geochemical processes that shape its environment. Conversely, virtually no aspect of environmental change remains untouched by human activity. Our societies continuously draw on materials and energy – the food we eat, the fuels we burn and the substances we use to produce the goods and services we enjoy. This conversion of materials and energy into desired products also inevitably brings with it the generation of waste products, many of which continue to be released into the environment, often with little regard for their long-term effects on the health of people and other species. As goods and services are produced and consumed, as waste products are generated, released and accumulated, as technologies, resource endowments and environmental quality change, society, too, changes – sometimes as a result of these other changes, sometimes as a driver for them.

Technological change has afforded humanity ever more clever ways to expand and tap into its resource base, seek and use limited materials and energy more efficiently, and cut down on the emission of many pollutants. Almost unfathomable improvements in public health, increases in life expectancies, and expansions of material wealth occurred in large parts of the world in just the past two centuries. It is therefore easy to see the temptations to extrapolate from our recent past into the future, seeing a world of increased technological prowess, perhaps even accompanied by broad social engagement in the decisions that shape our world. At the same time, however, considerable inequalities in wealth and well-being, and political and social strain between the ‘haves’ and ‘have-nots’, persist. A growing burden is placed on future generations to resolve the local and global challenges caused by rapid economic and population growth of the past and present. The fact that many of the resources available today will be further depleted, and many of the environmental sinks that help assimilate waste products become overburdened from continued accumulation, does not bode well for those who, in the future, seek solutions to the problems that are largely created and often ignored today.

In the midst of these tensions between, on the one hand, today’s activities and the opportunities they create, and, on the other hand, the constraints they place on the future of the human enterprise, we find environmental studies as a means to provide the science base on which to understand human–environment interactions and, as desired, guide resource use, production and consumption decisions, as well the release and accumulation of pollutants. Given the diversity of the challenges at hand, and the historical, social and cultural context within which these challenges are understood and addressed, it should not come as a surprise that interdisciplinary collaborations and methodological pluralism are prerequisites for anyone who hopes to get their minds, and hands, around the underlying and emerging complexities.

This book is a vivid reminder of the pervasiveness of that complexity and the rich

methodological and knowledge base that has been generated in environmental studies in recent years. Its contributors showcase how insights are generated by the interplay of theory, method development, and application, and how human–environment interactions are understood both at the conceptual level and through case-specific inquiry. Many of the chapters identify implications of these insights for investment and policy making. The role of the public – as recipients of advice, as final arbiters in the decision-making process, but also as providers and repositories of knowledge and as creators and curators of the social and institutional context within which advice is received and acted upon – permeates many of the studies presented here.

Part I of the book attends to this broader social context. Following this introduction, in Chapter 2, Simon Locke provides a historical perspective on the public's understanding of the environment and of environmental science, which are by no means the same. Instead, each shapes and is shaped by the other and, in many ways, environmental science, personal experiences of nature, environmental action and policy are closely intertwined. Yet, environmental science must be objective to meet scientific standards, and thus teased apart from the personal and social motivations that shape its applications. Herein lies one of the key challenges that permeate many of the subsequent chapters. That these challenges run deep and are not simply the product of our time but the larger cultural and historical context within which we understand nature and our role in it, is one of the points of this chapter – a point that is further elaborated upon by Derrylea Hardy, Murray Patterson, Huhana Smith, and Caine Taiapa, whose work spans two very different cultures – those shaped by Western thought and tradition, and those of the Māori Iwi and Hapū in Aotearoa/New Zealand. They identify a number of principles and research tools found to be effective in working in this cross-cultural context: hīkoi (walking the land); wānanga (intensive learning); oral narrative research; construction of a coastal cultural health index; mediated modeling; geographic information systems; and an interactive three-dimensional table combined with video and audio enhancements, as well as ecological surveying and statistical analyses of the causes of ecological degradation in local coastal ecosystems. The authors argue that none of these methods in themselves were sufficient, nor is any one framework or knowledge system necessarily appropriate for addressing all of the complexities that they faced in their research. Instead, Hardy and her collaborators make a strong plea for methodological and knowledge pluralism, whereby fundamental differences and commonalities are acknowledged and respected by teams of researchers and stakeholders.

How far culture influences knowledge about, values of and behaviors affecting the environment of course can, in itself, be the object of study, as Michael Paolisso demonstrates in Chapter 4. While there is general recognition that culture is defined by the shared beliefs, values, behaviors, materials and technologies of groups of people, he explores systematically how the generation, communication and implementation of shared group and individual level environmental knowledge, values and behaviors shape the perception of ecosystem restoration and of adaptation to climate change. Paolisso's applications of a cultural consensus approach to both of these issues are for communities of the Chesapeake Bay, in the Mid-Atlantic Region of the US, but have found wide applications in other locations around the world.

Communities are characterized by networks of people and the organizations they form, and, in turn, these networks shape interactions of communities with and decisions

about the environment. Communities here include the assemblages of people and their institutions in rural place, such as those studied by Paolisso, and the cities that are the home of ever larger numbers of people. As urbanization proceeds, new constellations of people and (civic) groups emerge that conserve, manage, monitor, advocate for, and educate their friends, neighbors and representatives about a wide range of quality-of-life issues regarding urban resources. Given the increasing role of these groups and individuals in urban natural resource management, researchers have sought to devise ways to understand the social and spatial interactions among actors working on urban environmental stewardship.

In their chapter on environmental stewardship networks, James Connolly, Erika Svendsen, Dana Fisher, and Lindsay Campbell draw on several cases, highlighting data collected on civic groups and volunteer stewards in New York City, to demonstrate a systematic mixed-methods approach to analyzing urban environmental stewardship networks. Reminiscent of the findings by Hardy and her co-workers in Chapter 3, they argue that the stewardship system is best understood by combining quantitative survey, network and spatial analytic methods with qualitative interview methods. In isolation, these data offer a narrow picture of the urban environmental governance system, but when each method informs the other a more comprehensive understanding of stewardship is possible.

As individuals, and the groups and organizations they form, increasingly shape policy and other environmental stewardship decisions, the important role of science and understanding of the environment discussed in Chapter 2 again is found to be center stage here. The perception of risk associated with climate change, for example, food security and safety, or a host of other environmental challenges, differ among groups and especially between experts and the lay public. In Chapter 6, Claudia Binder, Regina Schoell, and Monika Popp focus on differences in such risk perception, using a structured mental modeling approach to elicit risk perception as one element of many that shape livelihood-related risks. Following a detailed review of the literature in the field, and a distillation of that literature into a sequence of 'how to' steps, they apply the structured mental modeling approach to a case example of pesticide management in Colombia, South America.

Focusing on the theme of environmental stewardship and governance, Marta Olazabal and Diana Reckien note in Chapter 7 that understanding the complexity of socio-ecological systems, evaluating uncertainties and assessing potential management options are real challenges, particularly when the complexities in a system are distinctive and the data scarce, undefined or qualitatively poor. The authors present a participatory semi-quantitative interview and analysis method – fuzzy cognitive mapping (FCM) – as a tool to aggregate the accumulated experience, knowledge and perception of experts or actors. Experts and/or decision-makers are asked to translate their knowledge or experience into a network consisting of nodes and weighted interconnections, which represent states of the system and cause–effect relations. The resultant fuzzy cognitive map then encapsulates information on the main features of the network and enables scenarios of policy options or decision alternatives to be evaluated. In their chapter, Olazabal and Reckien present two case studies of fuzzy cognitive maps that deal with (1) urban management towards low carbon transitions in the city of Bilbao, Spain, and (2) impacts of extreme weather events and urban adaptation planning in the city of Hyderabad, India.

Increasingly, however, the field of environmental studies does not only serve to

collect and analyze data, organize information and knowledge, and guide environmental decision-making on the basis of the insights it generates. Instead, some researchers become integral parts of the decision-making process by making themselves part of the communities and actions they study. By doing so, they help close the loop that connects data collection, broadly defined, with system intervention, where intervention, in turn, generates data to be collected and analyzed. In the process of doing so, existing theories may be refined and new theories developed. However, because of being so closely embedded in the topics and communities that 'action researchers' study, special care must be taken by them to maintain a level of neutrality that ensures that their findings and theories abide by scientific standards. In his chapter on action research for coherently integrated sustainability policy design and implementation, Harn Wei Kua presents a two-stage process intended to address this challenge – one stage, in which research questions are formulated and addressed, and a second stage in which social change is initiated. He describes the tools used in those stages, and presents a case study on corporate social responsibility.

In Part II of this volume we turn to issues surrounding energy and material use by society, methods to trace their conversion as final products for consumption are generated and wastes are released, and as technologies change, economies grow, vulnerabilities of communities increase, and decisions need to be made on the interactions within society and among actors in different national or geographic contexts. Charles Hall sets the stage for this whirlwind tour through methods and applications by describing the fundamental role that energy plays in making any and all economic and social development possible, and in thus shaping the relations of economic and social systems to their environment. He points out that, until recently, cheap and seemingly limitless fossil energy has allowed most of society to ignore the importance of contributions from the biophysical world to the economic process – as well as the potential limits to growth. Specifically, his chapter centers on assessing the energy costs of modern-day society and its relation to gross domestic product (GDP). Hall carefully introduces the concept of energy return on investment (EROI) in ways that allow EROI numbers to be compared across various processes while at the same time remaining flexible, so that changes or additions to the universal formula can focus analyses on specific areas of concern. His analysis finds that the EROI of society's most important fuels is declining and most renewable and non-conventional energy alternatives have substantially lower EROI values than traditional conventional fossil fuels. At the societal level, declining EROI means that an increasing proportion of energy, and hence economic output, must be diverted to attaining the energy needed to run an economy, leaving less discretionary funds available for 'non-essential' purchases. Hall argues that declining EROI of traditional fossil fuel energy sources and the effect of that on the world economy are likely to result in a myriad of consequences, most of which will not be perceived as good.

Other constraints on the sustainability of the human enterprise come from its uses of water resources, which in theory are renewable but in reality are often severely constrained – geographically, temporally, and because of changes in water quality as a result of social and economic decision-making and property rights. In their chapter on global water flows, Kuishuang Feng and Klaus Hubacek make the important case that many of the products generated by the economy and exchanged among regions and nations require considerable amounts of water, either directly or indirectly, in their

production. To capture the various uses of water they describe, and then deploy, a multi-region input–output approach, which has become a popular tool for assessing virtual water flows along global supply chains, and for providing detailed sector-specific information of flows of goods and services within and between countries. In their study, Feng and Hubacek track not only direct water consumption and the place of consumption but also indirect water requirements, that is, water used in all upstream production steps for 35 select commodities. Their results show, for example, that developed countries, such as the USA, European Union (EU) countries and Japan, have a large amount of virtual water inflows through importing commodities from developing countries, especially China and India, which are exporting water-intensive products and at the same time are facing water shortages for their own domestic demand.

While Feng and Hubacek have chosen for their virtual water flow analysis a top-down approach, Till Zimmermann and Stefan Gößling-Reisemann in Chapter 11 present a bottom-up approach to the analysis of material flows along the life-cycle stages of products or product groups. These life-cycle stages comprise material extraction and refining, fabrication and manufacturing of semi-finished and final products, a use phase and end of life. Their focus is on the turnover of large amounts of products or product groups with the goal of providing detailed knowledge for sustainable management of materials. Their dynamic and prospective analysis provides information about future material demands following from market penetration of products as well as secondary material flows from their end of life. In such dynamic analyses the product life span is a key parameter. While in some studies (often implicitly) a simultaneous exit function of the life spans is assumed, alternative specifications may provide much more accurate results, especially for new and upcoming technologies with high growth rates. Zimmermann and Gößling-Reisemann discuss and use such specifications and show how knowledge about prospective stocks and flows can be used for a development towards a more sustainable material management, especially for building up the required recycling infrastructure for new technologies.

One way to conceptualize the various economic processes that use materials and convert energy is in analogy to the functioning of ecosystems, where the choices and behaviors of producers and consumers are tightly coupled with each other. Materials flows, in particular, can connect in intricate ways firms with each other, and with the social and biophysical environment in which they operate. Sometimes, these couplings are symbiotic, for example, when waste products of one firm are handled by another, thus providing resources for the latter, while keeping disposal and environmental compliance costs low for the former. The ‘industrial ecosystem’ that emerges and changes as materials and energy are converted is often a dense network of interacting producers, consumers, regulatory agencies and other actors, connected in often complex ways. Network analysis, as described by Junming Zhu and Lei Shi in Chapter 12, lends itself to capture not only the flows, organizations and social relations of different components of an industrial ecosystem in individual snapshots, but also the interactions and decisions that change those flows, organizations and relations constantly. Zhu and Shi begin with a brief review of important network concepts and theories. That review is followed by an analysis of network configurations of three typical industrial ecosystems and their connections, and a broader perspective on human–environmental interactions, as shaped by material and energy use. Some of these insights connect back to discussions in Chapters 6 and 7, where

the main focus was on networks of social actors, and their mental maps that shaped human–environment interactions.

A growing body of literature points to the need for models that address both environment and economy, and that also estimate or forecast the impacts of introducing not just new products but new and markedly different technologies from those already existing in the systems under study. Because most conventional economic and environmental models are calibrated to recent data reflecting current structures, processes and conditions, their standard turnkey application will need to be replaced by more comprehensive algorithms and procedures designed to explicitly accommodate shifts in technology, economic structure and environmental linkages. Randall Jackson, Christa Court, and Hodjat Ghadimi, in their chapter on ways to link environmental and economic modeling, emphasize one of the major challenges to this kind of modeling, that of dovetailing life cycle assessment and input–output modeling frameworks. They present two applications of their method. One of these applications is in the form of a comparative regional analysis of the state of West Virginia, USA, and Shanxi province in China to identify differences in responses of the two regions to similar technology transitions. The second application involves an assessment of the regional economic and environmental impacts of developing woody biomass as an energy resource in a rural region. The two projects differ in scale, technological focus, as well as temporal and spatial character, but share the need to develop or identify useful environmental data, in order to improve decisions on the addition or replacement of existing technologies, and to better assess the consequences of these technological transitions.

Development and diffusion of new products and technologies, turnover of capital stocks, accumulation of waste products, changes in demographics, growth of economies and changes in the affluence of people are all phenomena that unfold through time – often in relation to other dynamics. System dynamics, presented by Krystyna Stave in Chapter 14, is an approach to capture the relevant time-varying behaviors. In the environmental arena, system dynamics is used to examine why environmental systems exhibit particular dynamics, such as increasing or decreasing trends, oscillations or logistic growth. The methods and tools of systems dynamics are also increasingly used to support policy and management decisions about such issues. Towards that goal, system dynamicists examine the causal relationships, feedback mechanisms, tangible and intangible accumulations and material and information flows that comprise a system's structure. They explore places within the system's structure to change problematic behavior to something more desirable. Because opportunities to intervene often involve changes in human activity, a growing use of system dynamics is to promote stakeholder participation in decision-making. Stave introduces the principles and tools of the approach and describes the range of possible applications of system dynamics in environmental problem-solving. Following on that introduction, Chapters 15 and 16 present particular focal areas of research and applications, using, to various degrees, the system dynamics methodology. Specifically, in Chapter 15, Paula Antunes, Krystyna Stave, Nuno Videira, and Rui Santos focus on the uses of systems dynamics in environmental and sustainability debates, while in Chapter 16 María Eugenia Ibarrarán, Andrea Bassi, and Roy Boyd turn to an exploration of 'green growth strategies' in the Mexican economy, combining systems dynamics methods with input–output analysis of the kind discussed in Chapters 10, 12 and 13.

Given their abilities to capture the ways systems interact with each other and to reflect how the strength and direction of those interactions change over time, system dynamics models and the software used to develop them open up a wide range of opportunities to engage stakeholders in the modeling process and to interactively share the insights from the modeling process – not just the results – with end-use communities in the public, private and non-profit sectors. Paula Antunes and her collaborators discuss such uses of system dynamics modeling as a tool to inform, structure and facilitate public debates and stakeholder engagement in environmental and sustainability problems. They focus on the use of models along a continuum of increasing involvement of participants in the modeling process, from the use of simulations to foster learning and frame discussions about alternative policies and courses of action, to the engagement of stakeholders in system mapping exercises aimed at opening up debates and promoting ideas and their exchanges, to the practice of participatory modeling, where participants collaborate in developing a working model of a problem.

In contrast to Chapter 15, Ibarrarán and her collaborators discuss in Chapter 16 the use of system dynamics models to inform, from the outside, investment and policy-making. They also provide additional context for the discussion of the role of new products and new technologies presented in Chapters 11 and 12 in promoting economic growth, which is often portrayed as a goal of modern economic policy.

The standard argument about growth posits that growth opens opportunities for employment, raises material wealth and brings about the generation of financial resources to address remaining development challenges. However, as Ibarrarán and her colleagues point out, growth does not necessarily help address the problems created by growth, and thus economic growth should not be, and is not, the only objective for a country's development. Persistent unemployment rates as well as poverty, income inequality and natural resource depletion are often the by-products of growth, rather than eliminated by it. To respond to those challenges, many countries have been analyzing options to adopt green growth policies – policies that may foster economic growth, enhance environmental quality and promote jobs. As Ibarrarán and her collaborators emphasize, from a conceptual and technical perspective, it is difficult to model and assess policies that are expected to produce such broad impacts. The conceptual and technical challenges include, among others, how to model such policies to ensure that biophysical reality is taken into account when identifying possible policies or assessing their effectiveness specifically with respect to their impacts across social, economic and environmental dimensions. To address these challenges, they integrate two separate modeling techniques, that is, system dynamics and computable general equilibrium modeling, to estimate policy impacts across sectors and their macroeconomic effects. They illustrate the integration of policies in Mexico, related to improvements in the forestry, fisheries, water and transportation sectors, and discuss the effects of these policies for the economy as a whole. On the basis of their experiences and applications, Ibarrarán and her colleagues discuss the pros and cons of combining these modeling techniques, providing insights that extend beyond their specific case and that are of relevance to a broader scientific and modeling audience.

That ecosystems provide valuable contributions to the economy, for example, in the form of raw materials and energy and through waste assimilation, pollination, flood control and other services, is the backdrop against which many of the chapters in this book are written. The notion that those goods and services have value, irrespective of

whether they are priced on a market, is the basic tenet of Edward Barbier's contribution. He focuses on flood protection as one area of growing concern because of recent losses of these services and the associated damages to property, losses of life and livelihoods. Barbier begins with a brief review of past valuations of this benefit and illustrates the economic approach to valuing the storm protection service of estuarine and coastal ecosystems, using the example of mangroves in Thailand. In addition, he demonstrates, for the example of marshes in the US Gulf Coast, how hydrodynamic analysis of simulated hurricane storm surges can be used to determine the economic value of expected property damages that are reduced through the presence of marsh wetlands and their vegetation along a storm surge path.

Barbier's chapter points to the important role ecosystems have in protecting coastal regions, especially as coastal zone development proceeds and as climate change places the people and assets accumulating in those regions at ever greater risks. With a growing number of people living in urban areas and many of these areas being located near oceans or along other major water bodies, concern is growing, however, not only about flooding but a host of other extreme events, as well as the ability of urban areas to cut greenhouse gas emissions in order to combat climate change. Emissions reductions and adaptation were already a topic of Chapter 7, where Olazabal and Reckien applied fuzzy cognitive maps to urban environmental decision-making. Following on from these discussions, Johannes Schubert and Bernhard Gill in Chapter 18 broaden the methodological perspective on urban environmental action and explore how cities' energy and materials use as well as their emissions have been improving over time. Much of the answer to this question depends on the system boundaries that are employed and the methods to account for processes inside the urban area that must, inevitably, rely on provision of goods and services from urban hinterlands. The choice of bottom-up versus top-down approaches, already discussed in the context of water and material flow accounting in Chapters 11 and 12, surfaces as an important issue here as well. Schubert and Gill review findings from several complementary approaches to understanding urban environmental performance, such as urban metabolism and carbon footprinting, many of which are highly data intensive. In their own analysis of the energy use and carbon emissions profiles of Bavarian communities (Germany) they point at ways to reduce data demands and generate valuable insights that may help guide similar empirical analysis and inform strategies to promote reductions in material and energy use, as well as emissions.

Despite continued efforts to cut emissions and prepare for the climate change to which humanity has already committed itself, vulnerabilities remain. In Chapter 19, Deborah Thomas introduces terminology and its uses for the conceptualization of vulnerability, reviews various approaches to hazard and vulnerability assessments, highlights opportunities and challenges, and presents some emerging technologies that have begun to play a role in assessments. Using three frameworks to guide the discussion, including risk reduction, climate change and a capital-based disaster ecology model, Thomas showcases local and regional place-based assessments that rely on mapping technologies. Her presentation is focused on conducting vulnerability assessments such that valuable information is put into the hands of decision-makers, including the public, policy-makers, emergency managers and numerous other members of a community, with the goal of guiding vulnerability reduction. The engagement of these communities, Thomas contends, also vastly improves assessment quality, reflecting a theme found throughout



several other chapters in this volume – valuable knowledge for environmental decision-making resides in many different places in society, and being able to tap into those knowledge bases not only adds value to an analysis but can help advance the use of that knowledge for environmental improvement.

Different individuals and groups may choose different criteria by which to assess environmental improvement, or give different weight to these criteria. In many cases, performance with respect to one – say, economic costs – may be traded off against another – say, social justice. How to arrive at a representation of the criteria that are relevant to decision-making and how to compare them with each other across alternative plans or courses of action is the topic of multi-criteria decision analysis presented by Luís Dias, Sandra Silva, and Luís Alçada-Almeida in Chapter 20. They discuss the standard additive models, which are commonly used for their apparent simplicity, and note that these models require careful interpretation of the parameters involved, namely concerning normalization and weighting. As an alternative to the standard approach, they develop a partial information multi-attribute value model that avoids the need for setting exact values for criteria weights. An application of their model is demonstrated for the evaluation of the environmental performance of a set of Portuguese dairy farms and used to highlight specific issues of concern to multi-criteria decision analysis.

Taking the dynamic modeling piece of stakeholder interactions one step further, Casper Hartevelde and Anders Drachen present the use of games when addressing environmental issues. Contrary to popular belief, games are not only used to entertain. In fact, gaming has a long and rich history of being deployed for serious purposes, including explorations into challenging environmental management issues. Casper and Drachen provide an overview of the use of gaming on environmental issues by discussing the history of the domain, what it means to use gaming as a methodology, and by illustrating its application in a number of cases. The authors distinguish two main uses of games, namely, (1) to foster engagement and promoting learning in situations where environmental issues interface with humans (gaming as intervention tool), and (2) to extract qualitative and quantitative data about system behavior and/or about behavior/responses of humans that are part of systems (gaming as research method). In discussing evaluation methods, Hartevelde and Drachen place particular emphasis on state-of-the-art methods and techniques using game data, such as behavioral telemetry analysis and data mining, owing to their promise for maturing the field.

An entirely different strand of research on gaming has been developed in economics, where major emphasis is placed on theory-based analysis of the interactions among those playing a game. Here, a game is broadly defined to include the strategic situations in which each economic player must act based on their beliefs about what the other actors are likely to do, and vice versa. The actions of a polluter, for example, depend on her beliefs about the actions of an enforcement agency. Decision-makers are assumed to act in their own self-interest. Equilibrium occurs when all actors satisfy their self-interests simultaneously. Whether such an equilibrium exists and is unique has implications for the formation of cooperative agreements and coalitions, the design of institutions and the threats that may be employed to deter actions of other players, for example. In their chapter on transboundary pollution games, Henk Folmer and Pierre von Mouche attend to the case of players that do not, a priori, cooperate, and they explore the conditions under which an equilibrium exists and is unique.

In short, this book spans a rich array of methods and their applications in environmental studies. It portrays the diversity of challenges faced by researchers in the natural, social and behavioral sciences, and by decision-makers at local to global scales. The book is also a testament to the wealth of insights that can be generated when bridging the science–society gap, and it identifies not only the challenges of interdisciplinary and stakeholder-informed research but presents suggestions on how to avoid pitfalls and arrive both at better science and better environmental decisions. With knowledge of the methods and applications of this book in the hands of its readers, new frontiers open up for inquiries into the condition of human and environment systems, as well as their interdependencies, and novel opportunities will present themselves to advance environmental stewardship.