Introduction
Author(s): Wolfgang Lutz, Alexia Prskawetz, Warren C. Sanderson
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Introduction

WOLFGANG LUTZ
ALEXIA PRSKAWETZ
WARREN C. SANDERSON

There can be no doubt that population changes and environmental changes influence one another. Within the last few decades, this commonsensical observation has given rise to hundreds of scientific articles and reports and the flow shows no sign of abating. The premise of this volume is that this literature forms the groundwork for a new and interdisciplinary field of studies that we call P–E analysis.

This volume on the methodology of P–E analysis is motivated by two factors. First, because P–E analysis is a new field of studies it needs—like any other field of studies—to develop its own set of methods and analytical tools in order to arrive at meaningful substantive results. The second factor motivating this volume is the somewhat disappointing lack of consistent and generalizable findings after hundreds of P–E studies in different parts of the world over the past 15–20 years. We attribute this lack of more general findings not only to the inherent complexity of the issue but also to the lack of broadly accepted reference methodologies and standards that in other disciplines make it possible to compare one study to another and eventually obtain more general insights. Without such common points of reference, there is confusion and individual studies can at best be of anecdotal importance. This is where the present volume hopes to make its contribution. It presents some key approaches that have proven useful in P–E analysis and hence moves the field a bit further toward methodological consolidation.

The methods and approaches included in this volume span a broad range from highly quantitative dynamic models to decomposition methods and various qualitative approaches. This list of methods does not claim to be exhaustive, but to our knowledge it presents the first systematic collection of P–E methodologies. When a field is young and just taking form and when the specific research questions are as varied as they tend to be in P–E analysis, it is important to consider a broad array of possible methods, many of which stem from other fields. This desire for methodological plurality does not contradict the need for standards. Indeed, the plurality of approaches becomes most useful if they all refer to certain standards—such as comparable population measures by age and sex—and hence can highlight different aspects of the same observed phenomena.

In this introductory chapter we first discuss the question whether P–E analysis deserves to be called a field. Next we present a broad conceptual framework for P–E analysis that also helps to assign the different chapters of this volume their proper places in the analysis of the bigger picture. We then briefly mention some key dimensions of P–E analysis and indicate how the chapters relate to them before we finally present the structure of the volume and give a short summary of each chapter.

Is P–E analysis a specific field of study?

This book is built on the premise that P–E analysis is indeed an emerging and distinct field of scientific analysis. What justifies this statement? There seem to be three criteria that in combination justify calling a certain body of research studies a distinct field: (a) a critical mass of people that work on these issues, (b) a set of joint research questions, and (c) a set of common methodologies. For some fields of scientific studies all three criteria are being met; for other fields only the first two. Take Japanese studies as an example of a field that nobody would challenge as being distinct. It clearly has a critical mass of scholars working on Japan and has a common research focus although there hardly is a common methodology. The range of methods applied may include linguistic, geographic, anthropological, and economic approaches. In other fields such as nuclear physics or demography there is a set of standard methodologies in addition to the critical mass and the common object of analysis. How do these criteria apply to P–E analysis?

(a) Mention has already been made of the several hundred P–E studies published in the formal literature. It is hard to come up with a more precise figure because the bounds of the field are fuzzy and one must largely rely on self-identification of the authors. Another indicator of an emerging critical mass is the fact that in the last decade international population conferences—especially the PAA (Population Association of America) and IUSSP (International Union for the Scientific Study of Population) conferences—have consistently had several sessions on P–E topics on their agendas. Also funding agencies have been launching special calls for P–E studies and one (the MacArthur Population–Consumption–Environment Initiative) has systematically funded case studies in the field for many years. IIASA, IUSSP, and UNU (United Nations University) have recently launched a Global Science Panel on Population and Environment that largely follows the example of

US–NAS panels at the international level and produces high-level input on the topic to UN conferences such as the Johannesburg Summit on sustainable development. Finally, an increasing number of institutions of higher education offer courses on population and environment as part of their standard curricula. Taken together these developments show that indeed a critical mass has been building up in the field of P–E analysis.

(b) The unifying research question is probably the easiest part in identifying P–E analysis as a field. The field is defined by two rather simple research questions: What are the impacts of changes in the human population on the natural environment (P–E)? and What are the impacts of changes in the natural environment on the human population (E–P)? These research questions—as with research questions in any other field of studies—need to be operationalized in a specific context, particularly with respect to the specific environmental aspects considered. But these two rather unambiguous research questions are probably the most powerful unifying element for defining the field.

(c) The range of methods applied for addressing the P–E research question is still heterogeneous. There is no standard methodology that defines the field and there probably will not be a broadly accepted standard in the near future. This volume is the first attempt to systematically address the issue of methods in P–E analysis. We hope it will contribute to greater clarity and compatibility of future P–E studies. The volume does not attempt to establish a standard set of methods but the two recommendations discussed in the concluding chapter, namely the need to be explicit about both the P and the E dynamics and to be specific about which mediating mechanism one addresses, seem to be necessary next steps in order to make sure that different studies in the field can be meaningfully related to each other.

Conceptual framework for P–E analysis

Fields of study are defined by philosophy as well as methodology. Our discussion of P–E methodology in this chapter is based on our broader view of the subject matter, or what might be called our P–E analysis philosophy. For clarity, it is useful for us to state our conceptual positions clearly before proceeding.

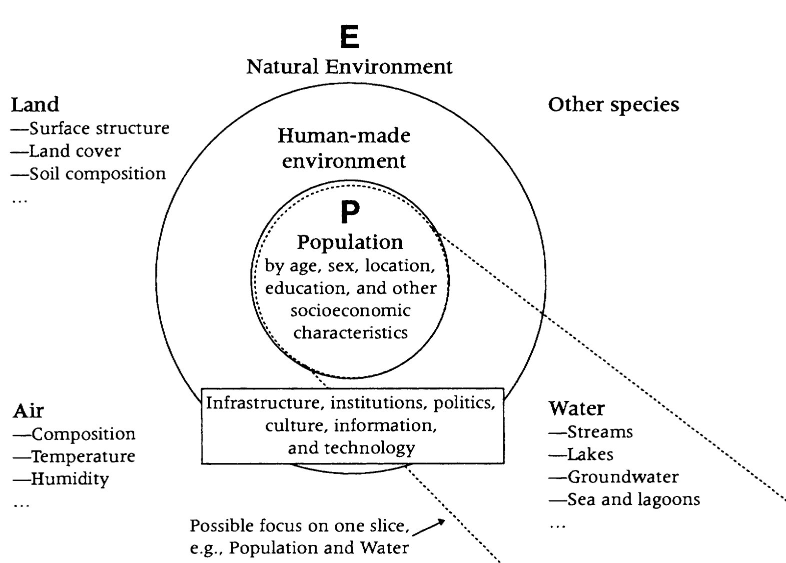
In the presentation of conceptual models in the P–E field, one typically finds different boxes connected by arrows. Hence the typical approach, which is also behind the linear identity equation known as the I=PAT or Ehrlich–Holdren identity (see discussion in O'Neill, MacKellar, and Lutz 2001), shows population as a box influencing the environment (another box). Several other conceptualizations directly or indirectly link population and the environment through consideration of various kinds of intermediating processes (see, e.g., Bilsborrow and Okoth-Ogendo 1992;

Bilsborrow and Carr 2000; Jolly 1994; Marquette and Bilsborrow 1999; Cohen 1995). We will not review any of these approaches in detail but instead go to a still more general level in which the human population is not seen as something outside nature (a separate box) but as just one distinct species on this planet in which we happen to have a special interest because we belong to it.

It seems very strange to think of the human population and the natural environment as two independent autonomous systems. One cannot draw a line about nature and see the human population as outside this line. Nothing is independent of the environment, including the human species, which is part of nature and in all basic life-supporting functions depends on the environment. Rather than viewing population–environment linkages in terms of a linear causal chain of separate boxes, it should be visualized as a series of concentric circles where the inner circles are fully embedded in the broader ones.

Our view is presented in Figure 1. In the innermost circle we have the human population classified by individual characteristics, such as age, sex, location, education, and other socioeconomic characteristics. We call the next larger circle the human-made environment. It includes a wide variety of items from infrastructure, the economy, the government, politics, social structures, traditions and history, technology, and information.

FIGURE 1 The human population and the human-made infrastructure as being fully embedded in the natural environment and subject to the laws of nature. P–E studies may analyze certain sectors (see dotted lines) or try to comprehensively study the full system.



The outermost area contains the natural environment and it includes everything from the levels of tropospheric and stratospheric ozone, to biodiversity, to the availability of solid waste dumpsites, and the accessibility of beautiful mountain views. In order to deal with it in a systematic manner, it can be classified into broad categories having to do with air, water, land, and other species on this planet.

Figure 1 emphasizes that every life on earth, every economic activity, and every kind of development is embedded in the laws of nature. In this sense, the environment is seen not only as a constraint, but also as the basic life-support system that makes all human activities possible. It is simply impossible to think of any human activity as being independent of the physical environment; changes in this environment affect humans.

Within the sphere of the human-made environment, people are the agents. They are the ones who conduct the activities, develop routines, traditions, cultures, knowledge, and infrastructure, and change the natural environment. People are the victims of environmental degradation, with the vulnerability to such change being mediated through the human-made environment. There is no doubt that human life is dependent on certain forms of social and economic activities, and that further development of these activities makes a better and longer life on earth possible for more people. This is why the population is fully embedded in the circle of human-made environment, which comprises social and economic activities. There is no human population without production and consumption.

At the center of Figure 1, we have placed the human population classified by individual characteristics. Traditional demographic analysis focuses on the age- and sex-distribution of the population. We believe that, in most contexts, educational attainment and location (such as rural/urban place of residence) should be added to that list as important characteristics of the population. Interactions between the human population and the natural environment go in both directions and in both cases the impacts are mediated through human-made infrastructure, development, and institutions.

In our view, a P–E study can either try to analyze the salient features of the full environmental circle—as has been done in the comprehensive PDE studies described in the final chapter in this volume—or can be represented as a slice (see, e.g., the sector focusing on population and water in Figure 1) of the concentric circles that contains elements of both P and E, as has been done in most of the other chapters. Naturally, every such slice linking P with a specific aspect of E will contain elements from the human-made environment as well.

Dimensions of P–E analysis

P–E analysis may be thought of as a chair with four legs: (1) P (population dynamics), (2) E (environmental dynamics), (3) influences of P on E, and (4) influences of E on P. All four aspects can be studied scientifically either in separation or jointly. A full P–E study should consider all four aspects jointly especially if it is intended to be a comprehensive study. But even if the study only focuses on a certain slice in Figure 1 and even if it only looks at one direction of the influence, it is still preferable to be explicit about both the dynamics of P and the specific dynamics (e.g., hydrology) of the aspect of E studied, as will be discussed in the concluding chapter. So far the overwhelming majority of P–E studies have focused on one of the four legs, namely (3) the influences of P on E. This is clearly legitimate and useful for a better understanding of specific mediating mechanisms as long as it is seen as part of the bigger picture of multi-dimensional P–E interactions. Many of the chapters in this volume focus on this most prominent and most popular aspect, while others go beyond this and propose different ways to link this aspect to the other three legs of the chair.

Population dynamics

In classical demography, populations are disaggregated by age and sex. The cohort-component model of population projections is the appropriate way to describe the population dynamics by age and sex. It is possible and interesting to go beyond this in a number of ways. One possibility is to aggregate populations into households as in the O'Neill and Chen chapter in this volume. As O'Neill, MacKellar, and Lutz (2001) and the O'Neill and Chen chapter show, it makes a difference to emissions forecasts whether people or households are used in forecasting. Another way to proceed is to further subdivide the population by other dimensions such as rural/urban place of residence, education, ethnicity, labor force participation, and the like. To use education as a dimension of disaggregation is particularly relevant because educational attainment has important effects on fertility, mortality, and migration and plays a role in population–environment interactions.

Many P–E studies tend to view population only in terms of total size or in static terms, that is, as a given distribution. Others tend to study it only in terms of one of its components of change, for example, only looking at the number of in-migrants without considering natural population dynamics. None of these approaches captures the full dynamics of P, which—as most demographers tend to believe—should at least include the full dynamics of the age and sex structure over time and if possible even additional dimensions. There are easily available demographic tools for doing this.

Location

Much P–E analysis is concerned with the spatial distribution of the human population. Since location is not static and many people are on the move, this typically involves efforts at understanding the dynamics of migration and how it is affected by environmental conditions and how it affects environmental conditions. There are countless studies on the interactions between migration, land use, and natural resource consumption (Marquette and Bilsborrow 1999). In this volume both Cramer and Curran discuss steps in this direction of studying P–E interactions along the location dimension. Curran's chapter makes it clear that, for some problems, we have to understand not only the number of people who are living in each area, but also the migration status of those people. It would be a challenge to incorporate concepts like social capital and social embeddedness into the familiar cohort-component framework.

Environmental dynamics

Like population, the environment has dynamics of its own. As has been discussed above, the kind of environmental dynamics described will depend on the specific aspect of the natural environment to be considered, that is, the slice to be chosen from Figure 1. One important distinction to make in dealing with the environment is the difference between stocks and flows. Usually, the environment is thought of as a stock, while human effects over some period of time are flows. For example, the emission of greenhouse gases during a particular period is a flow, while the climate at a certain date is considered a stock that is influenced by that flow. Many other things, of course, influence the stock as well. In the Chu and Yu chapter, the cutting down of the rainforest is the flow and biodiversity (which decreases with the loss of rainforest area) is the stock.

There are exceptions to the rule that we should be clear about in the distinction between flows and stocks. Transitory air pollution is an example where the flow and the stock are the same thing. Many studies of tropospheric air pollution, such as Cramer's, fall into this category. As with population dynamics it is important to adequately choose the time scale of describing the environmental dynamics in trying to capture the P–E interactions.

Interactions and feedbacks

The interactions and feedbacks between the various elements of a P–E analysis are crucial to our understanding. Some P–E analyses deal with causation in one direction, either from population to the environment, or from the environment to population. Others allow causation to run in both directions. Where there is bi-directional causation, there can be negative or positive feedback loops. Negative feedback loops cause perturbations to be dampened and die out. Positive feedback loops cause perturbations to be reinforced. In this case, small initial changes can lead to large induced effects. Cramer's chapter contains an example of an analysis with a negative feedback loop. Other things equal, larger populations generate more pollution and the greater the level of pollution, the lower the rate of population growth.

P–E analyses sometimes produce nonlinear dynamic systems. In addition to generating positive and negative feedback loops, these systems produce a number of interesting phenomena that have clear counterparts in the world. The closer integration of the theory of nonlinear dynamic systems and P–E analysis could have a big payoff. The small PEDA model in the Lutz et al. chapter is an example of this (see also Milik et al. 1996; Gröller et al. 1996; Gragnani et al. 1998).

Spatial scale

Scale enters P–E analyses in four ways: (1) spatial scale, (2) temporal scale, (3) scale of the analysis, and (4) the relationship between the scale of human activities and their environmental consequences. We distinguish three levels of spatial scale, the global level, the meso (national or regional) level, and the local level. P–E analyses are being conducted at all three scales, and these should be seen as complementary rather than alternatives. In this volume the chapter by O'Neill and Chen discusses carbon dioxide emissions at both the global and meso (national) levels. The Curran chapter deals with P–E analysis on a local level. In the future, we might see the development of new methods that include interactions across spatial scales.

Linking studies conducted at different scales is a key challenge to the field because only through this linkage can we get a full picture of the nature of P–E interactions. There are forces operating across spatial scales in both directions: individual and community-level behavior accumulates to national and even global impacts; on the other hand global changes such as climate change will affect the lives of communities and individuals. The meso, that is, national, level also plays a key role in this process because this is the level at which many of the institutional, economic, and political mechanisms operate.

Temporal scale

Temporal scale is another important dimension of P–E analyses. Where there are no feedbacks from the environment to fertility and mortality, and migration is unimportant, population sizes and age structures can be forecasted quite accurately for a few decades because most of the deaths in the forecast period will be of people who are alive at the starting date, and most of the births will be to women who are alive at the starting date. As the duration of the forecast increases beyond a few decades the range of plausible outcomes increases substantially. Significant migration or feedbacks to fertility and mortality add uncertainty to forecasts even twenty years ahead. Where possible, population forecasts should include some measure of their uncertainty and the increase of uncertainty over time.

To understand environmental change, we sometimes need to view time differently. There is such significant short-run variation in magnitudes having to do with rainfall and drought that they are best considered on a monthly or weekly basis. One month with no water to drink or with serious floods can have an important effect on a population, even if the average water supply for the year is normal. The climate of a place, which affects its rainfall and drought patterns, normally changes slowly. A twenty-year forecast might reveal only the beginning of what ultimately could be substantial climate change. The interaction of time scales is an important phenomenon. Sometimes population change and environmental change occur at very different speeds. The mathematical approach called "geometric singular perturbation theory" can be applied to study such systems whose variables change with very different velocities, that is, systems that exhibit slow–fast dynamics (see for example, Milik and Prskawetz 1996; Milik et al. 1996).

Feedbacks are also affected by both the time horizons and the time scales of the dynamics considered. Therefore the time horizon of the analysis and the temporal scale should be related. The specific choice will depend on the nature of the question; there may be tradeoffs because it may be difficult in practice to consider 200 years (an appropriate time horizon for climate feedbacks) in monthly steps (an appropriate scale for floods and droughts).

Analytical complexity

Another important question for P–E methodology is the scale or better the complexity of the P–E analysis itself. Some P–E models, such as Targets (Alcamo, Kreileman, and Leemans 1998), contain many thousands of equations. Others such as the reduced PEDA model contain only three equations. A special issue of the journal *Mathematical Population Studies* (Rogers 1995) was devoted to answering the question of whether simple or complex population models produced better forecasts. The answer was that the complexity of the tool that was deemed best depended on the details of the problem.

The chapter on the PEDA model in this volume signals a direction in which future research could be fruitful. The question posed there is whether small models and larger models could complement one another in deepening our understanding of P–E interactions. The chapter demonstrates such a complementarity. In the future, we may think of P–E studies as producing not a single model, but a set of consistent models at different scales, each of which allows us to see clearly different aspects of the underlying

P–E reality. Simple models isolate and more clearly illustrate key dynamics, whereas complex models have greater realism, include more control (policy) variables, and can explore more potential feedbacks.

Scale of human activities and environmental abundance

Still another sense in which scale is used in P–E studies is in terms of relationship between human activities and the ability of the environment to support those activities on a sustainable basis. Scale, in this sense, requires the definition of constraints. The contents of this volume are very different from what they would have been had it been written two or three decades earlier. Previously, there was concern that humans would run out of raw materials. Various studies warned us of how many years it would take before we ran out of oil, iron ore, and copper. The constraints that people saw were constraints of raw material availability.

Today, we do not worry very much about these nonrenewable resources. Generally, they are priced and allocated well enough by markets. These markets look well into the future. Expected future shortages are signaled by increases in price, which have the effect of reducing contemporaneous demand and increasing the incentive to search for more supply and for substitutes.

Markets and institutions

We see the most important P–E problems of the future as those for which markets do not exist or where they function poorly. Cramer's chapter concerns local air pollution. The O'Neill and Chen chapter deals with energy use and CO_2 emissions. The chapter by Chu and Yu deals with biodiversity, and Curran's chapter deals with common property coastal ecosystems. All four chapters deal with cases in which markets do not exist. This is not to say that governments cannot use economic tools to help solve environmental problems in those areas; they certainly can. But social control through governments or other institutional arrangements is the basis for maintaining environmental systems where markets do not exist.

Where markets do not exist, it is not simply a matter of producing pseudo-markets by putting valuations on non-priced portions of the environment. The Smil chapter argues cogently that such an approach is doomed to failure. Smil argues that valuation of non-priced renewable resources must result from a social process. Further research could focus on the nature of that social process and how it relates to the social control of the environment.

The constraints of renewable resources are mediated through institutions. The McNicoll chapter discusses the importance of these institutional arrangements in P–E analyses. McNicoll suggests that we think about institutional arrangements in terms of how they define P–E systems' boundaries, monitor environmental change, and value the outcomes of policy interventions. Each of these could be an interesting area of research in its own right.

Normative versus positive approaches

P–E analyses can have normative and positive aspects. The normative aspect of a P–E analysis is the portion that discusses how things should be. The positive aspect of a P–E study is the discussion of the way things are or will be, under certain circumstances. Normative aspects of P–E studies have generated much heated and inconclusive debate. Sustainable development is an often-used normative concept, but its common definition, meeting the needs of the current generation without jeopardizing the ability of future generations to meet their needs, has not led to a generally accepted empirical formulation. Economists often use the normative concept of maximizing the discounted value of current and future utilities. This has led to an unresolved debate on whether discounting is appropriate and what the correct discount rate should be. The McNicoll and the Chu and Yu chapters comment on the difficulties of finding a suitable normative criterion. An important item on the agenda of P–E research is the formulation of such a criterion.

More generally, it can be observed that the P–E field still suffers in terms of its scientific rigor from the fact that many authors enter it with a predefined normative goal and often use rather simplistic methods to "scientifically" argue that point. Here a clear distinction between positive approaches and explicitly stated normative criteria would be helpful. We will never reach a perfect separation between normative and positive aspects since any choice of categories and variables depends on our implicit preconceptions, but certainly further progress toward clearer distinctions can be made.

Vulnerability

An important field for future research is the mortality and morbidity consequences of environmental conditions. Urban air and water pollution can affect health and longevity. Global climate change can alter the areas in which malaria-carrying mosquitoes can thrive and therefore affect death rates from malaria. Global health changes attributable to human-induced alterations in climate have been studied in some large P–E models such as the Targets model (see Alcamo, Kreileman, and Leemans 1998).

McNicoll suggests the approach of disaggregating populations according to whether they are gainers or losers from some environmental policy or condition. Climate change is an interesting illustration of this. Recent work (Fischer et al. 2001) shows that, on balance, agriculture will be helped in some of the richer countries of the world and harmed in some of the poorest. The research on population and emissions discussed in the O'Neill and Chen chapter can be combined with the winner/loser disaggregation suggested by McNicoll to provide a more complete picture.

An important motivation for studying P–E interactions is to find ways of alleviating poverty, yet poverty has often been overlooked in these studies. The PEDA model of Lutz and Scherbov (2000) and the Lutz et al. chapter point us in that direction. The large and small PEDA models explicitly consider the inequality in the distribution of food. One dimension along which P–E methodology could evolve is to develop further ways of considering such distributional questions.

Uncertainty

The methodology of P–E analysis could be broadened to consider uncertainty more explicitly. Recently, steps have been taken in this direction for P through the use of stochastic population forecasting (see Lutz, Sanderson, and Scherbov 2001; Lee 1999; Lutz, Sanderson, and Scherbov 1999). The latest Intergovernmental Panel on Climate Change assessment (Nakićenović et al. 2000) develops one way of considering uncertainty in P–E analysis. Instead of formulating a probabilistic analysis, it proposes a set of internally consistent storylines (dynamic scenarios) in which both population and CO_2 emissions (and therefore climate) change. Incorporating uncertainty explicitly into P–E analyses is an important step in developing a P–E methodology.

In the future, it could be productive to enrich our understanding of P–E and E–P interactions by including concepts from ecology such as surprise, resilience, adaptability, and adaptive management. The concept of surprise, while related to the concept of uncertainty, is different. We can be surprised about single elements of P–E systems. Vulnerability, resilience, adaptability, and adaptive management, on the other hand, are best applied to entire P–E systems.

Structure of the volume

Each of the next four chapters in the volume focuses on one aspect of the environment: local air pollution, global climate change, coastal ecosystems, and biodiversity. The scale of the analysis varies from local case studies presented in the chapters by Cramer and Curran to a national case study of the United States in the chapter by O'Neill and Chen to a global case study of the extent of biodiversity decline addressed in the chapter by Chu and Yu. The methodologies surveyed vary from simulation models and simple analytical models to statistical models and decomposition analysis. Two of those chapters present new empirical case studies, one using fixed-effects panel models (Cramer) and the other a decomposition analysis (O'Neill and Chen).

The three subsequent chapters address the question of defining and managing P–E systems (McNicoll), linking information on population and environmental outcomes (Evans and Moran), and valuing environmental services (Smil). Hence, in contrast to the first four chapters that assumed the existence of the concentric circles in Figure 1, these three studies are concerned with drawing the circles correctly and defining the elements of the circles. The penultimate chapter of the volume is devoted to a simulation model on P(opulation) E(nvironment) D(evelopment) and A(griculture) in sub-Saharan Africa and takes up the issue of comparing large- and small-scale models. In contrast to the other chapters in the volume it is not restricted to one environmental aspect, but considers land and water simultaneously. It also applies a more detailed population decomposition.

The volume concludes with a chapter that illustrates a way toward consistent and comprehensive meso-level P–E case studies that in the end lead to a few general recommendations for the future.

Next we briefly summarize the chapters in this volume.

The chapter by James Cramer reviews methods and models that are used to link *population growth* to *local air pollution* and presents an econometric case study applied to counties in California. Recalling the well-known I=PAT identity, Cramer considers two intervening factors that mediate the link between the population module (as represented by the trend in population growth) and the environment module (the trend in emissions). These are affluence as measured by per capita income and regulatory effort for emissions of specific sources. The nature of the link itself is determined by the source of the emissions. Moreover, since air pollution itself will affect humans, Cramer suggests a model of reciprocal causality and thereby considers the two-way link between the population and environmental module.

After a short methodological review on simulation versus statistical models, he presents an empirical, statistical case study that relates population growth and atmospheric emissions in California for the period 1975–95. In a first model Cramer considers the effect of the trend in population growth on air quality, controlling for trends in intervening factors. In a second model he considers the reverse causality, that is, the effect of the level of air quality and the intervening factors on the trend in population growth and the intervening factors themselves. For both models he applies a fixed-effects panel approach. From the first model it may be concluded that population growth will have a large impact on emissions for sources related to consumption and small effects for sources related to production. Within the second model Cramer shows that the initial level of emissions influences the intervening factor of regulatory effort and also negatively affects population growth. Obviously this approach of using the same set of variables to test for reciprocal causality, that is, to explain intervening variables and population growth in terms of the intervening variables and population growth itself, may be criticized as noted by Cramer himself. However, the analysis is unique in the way that it attempts to shed light on the reciprocal relation between the population and environmental modules.

The chapter by Brian O'Neill and Belinda Chen links various household characteristics to energy use in the United States. In the first part of the chapter the authors show that households of different sizes and with different age compositions of members tend to use energy at different rates. This much is known. It is not unusual in the energy studies literature to use demographic characteristics as explanatory variables in the analysis of cross-sectional household data. What is new here is the exploration of the possibility that because the composition of the US population according to these household characteristics has been changing over time (and will likely continue to change in the future), accounting for demographic effects at the household level may be important to understanding and projecting trends in aggregate energy demand. O'Neill and Chen use the technique of standardization to decompose historical trends in household energy use into contributions from changes in the distribution of households by various types and changes in the size of the population. They find that changes in household distributions by size, age of the householder, and the age composition of family members between 1960 and the mid-1990s may have been responsible for about 15 percent of recent total household energy use. Based on the historical data, they derive relationships that can be applied to household projections, and estimate that compositional changes may increase energy demand by 20 percent over the next 50 years.

The main strength of this approach is that aspects of population composition are brought into the analysis, moving beyond the traditional focus on population size alone. O'Neill and Chen's results show that composition matters, and therefore that the study of population–energy use links at the household level is probably important to understanding trends in aggregate energy consumption over time. This linking of the micro and macro scales of analysis bridges a gap in the study of energy use and suggests that projections of aggregate energy demand, which are important to the study of future climate change, could be improved by using household-level survey data to inform relationships at the national level. As the authors note, there are weaknesses to their study as well: while this application of standardization is not subject to many of the shortcomings of past decomposition analyses applied to energy and emissions, it still retains the assumption of linearity—in this case between population composition and energy use. It is possible, however, that household distributions would themselves be expected to change the typical level of energy use by each household type, for example through a macroeconomic feedback. A second problem is that the estimation of the effects of future impacts of compositional change on energy use is hampered by the lack of detailed household projections, and therefore must rely on summary measures such as average household size. By drawing attention to these weaknesses, the authors mark a clear path toward improved analyses of demographic effects on energy consumption.

The chapter by Sara Curran focuses on the link between population growth as caused by *migration* and *coastal ecosystems*. Social networks and social capital as they relate to the dynamics of migration as well as the use of ecosystems are the most salient intervening factors that link population and the environment. Since coastal ecosystems are mostly open access resources, they are especially under pressure by migration. It is therefore imperative, as Curran notes, to understand how migration and common property resource management interact to affect environmental outcomes in coastal ecosystems.

In the first part of the chapter Curran focuses on specific characteristics of the population and the intervening factors, that is, the two concentric circles in Figure 1. While the environmental literature treats migration mainly as an aggregate stock, Curran stresses the importance of various forms of migration (e.g., return, repeat, circular, temporary) and characteristics (e.g., age, life course stage, human capital) of migrants. These various dimensions of migration together with the migrants' social capital and social network as well as their remittances will ultimately determine the impact on the ecosystems in the destination and origin regions. Common property resource institutions constitute the link between the population and the environment and are defined by Curran as the formal or informal set of social relations governing people's relationships within a particular ecosystem as they relate to resource exploitation. Social bonds among people and the embeddedness of human actions within social relations are regarded as central solution concepts to the tragedy of the commons in the human ecological literature. Migration is then often regarded as weakening those social bonds and social capital and therefore as having negative effects on the ecosystem in the destination area.

In the second part of the chapter Curran presents six case studies in developing countries that explore the link between migration and coastal ecosystems. The first two examples refer to research in the Galapagos Islands in Ecuador and in Goa in India, illustrating that migrants' selectivity has a profound impact on the coastal ecosystem. As in the contribution by Cramer, she considers as well the reverse causality from the change in the coastal ecosystem to future migration streams. Curran then introduces two further case studies, one in Ghana and one in Guatemala, to show how migrants' social networks and migrants' embeddedness in the destination and origin regions may have varying effects on the coastal ecosystem. The final two case studies, in Vietnam and Micronesia, are devoted to the role of migrants' remittances on the ecosystems in their countries of origin.

The next chapter in the volume, by C.Y.C. Chu and R.-R. Yu, focuses on the interrelationship between *population growth* and *biodiversity decline*. Before narrowing the environmental concern to biodiversity, the chapter starts with a short introduction on the more general relation between population size and carrying capacity. Simple Malthusian models have mostly neglected the role of intervening factors like institutions and technologies that may increase the earth's carrying capacity. However, as stressed by Chu and Yu, human beings paid high prices for these innovative processes and while they have succeeded in mitigating the resource pressure, these changes often caused environmental damage. From this introduction it follows that the most important intervening factor that links population growth to biodiversity is human institutions.

In the second part of their chapter Chu and Yu list five main problems that are related to biodiversity decline and its solution. The first problem, population pressure in developing countries as a result of population growth and population distribution, leads to deforestation in order to increase farmland and human settlements. Recalling our proposed metamodel in Figure 1 the following four problems may be assigned to the human-made environment. These are the path-dependence and lock-in effects of economic processes, the difficulties of valuing biodiversity decline, assessing the benefit to future generations, and obtaining international coordination in a global environment. After discussing each of these problems in detail Chu and Yu present global and local evidence of biodiversity decline. They conclude that population pressure in developing countries implies agricultural expansion, which in turn leads to deforestation and hence biodiversity decline. On the basis of this evidence they review and propose several policy proposals all targeted toward the intervening factors that link population pressure and biodiversity decline in developing countries. These are, for instance, the establishment of property rights specifications, the introduction of modern agricultural practices, and economic development. They suggest that developed countries that set the rules of the game should also bear costs. As these considerations nicely demonstrate, the link between population growth and biodiversity decline in developing countries may be caused by intervening factors that are driven by those outside the considered P–E system, that is, by developed countries. On the other hand this study also demonstrates that only by careful consideration of the intervening factors can one propose policies that are able to break the vicious spiral between population pressure and biodiversity decline in developing countries. However, as mentioned in their conclusion, the most important future research in this area is to construct measures of biodiversity decline.

The chapter by Geoffrey McNicoll reviews the difficulty of institutional designs necessary to manage the P–E systems. He starts by discussing three prerequisites to establishing successful institutions. These are the need (a) to delimit boundaries of P–E systems, (b) to monitor population and environment change, and (c) to evaluate environmental and demographic change. Boundaries that delimit the relevant population as well as the environment to be studied are difficult to draw physically and are often the issue on which the principal political struggle takes place, as noted by McNicoll. On the population side McNicoll distinguishes between three groups of populations that are involved: (1) persons who directly affect the environment, (2) persons benefiting from those impacts on the environment, and (3) persons harmed by the change in the environmental state. In practice these three groups often coincide or at least two of them are often identical. The second issue of monitoring the population and environmental change is similarly difficult, as already outlined in the chapter by Chu and Yu in the case of biodiversity. However, it is imperative to value the change in the environmental state and humans' contribution to these changes as well as humans' well-being in order to design any institutional regulations. The third argument of valuing environmental and demographic change is of equal importance. McNicoll distinguishes between various concepts such as, for example, present time bias or adaptive preferences, that is, where current environmental states will influence tastes and preferences. Hence, while all previous chapters are concerned with the positive aspects of P–E systems, McNicoll's chapter is the first one that stresses the necessity of normative aspects.

In the second part of the chapter McNicoll suggests a design of governing institutions for P–E systems. In particular he stresses that while common pool resource management is often the most intensively studied one, most P–E systems deviate from the character of common pool resources. The inherent symmetry of common pool resources between those who gain and those who have to bear the costs cannot be observed in most environmental systems. McNicoll then lists three types of policies that may be used to govern P–E systems. These are mechanisms that regulate transfers and compensations to those affected by environmental change, sanctions for the population not obeying the rules, and excludability when population growth is involved. He concludes with prospects for P–E system management recognizing that the management task is made more difficult if there are unclear or contested boundaries, large numbers of participants, complex system dynamics and outcome indicators, or unequal stakes by participants.

In their chapter Tom Evans and Emilio Moran explore the potential of spatial data analysis to link social data and biophysical factors in order to assess landcover change. The pattern of land settlement, land use, and types of land tenure act as intervening factors that will determine the spatial linkage of social and environmental data. In the first part of the chapter the authors give an overview of the methodological issues that are related to the spatial unit of analysis. Most social surveys are conducted on the individual, household, community, and regional levels; but, as the authors stress, the household level is the best suited since it is at the household level that many land-use decisions are made. For landcover characteristics the spatial unit of analysis is mostly determined by data availability and less often by the research question. The difficulty is then to link a well-defined group of people to a specific area of the landscape to understand how individual decisions and landholder characteristics may influence landcover change.

In the second part of their chapter the authors review the results of linking social and biophysical data in three study areas that are characterized by different land settlement patterns and land tenure systems. The three study areas are Altamira in the Brazilian Amazon, Monroe County, Indiana in the American Midwest, and Nang Rong District, Buriram Province in Northeast Thailand. In Altamira, where landholders cultivate one parcel, a one-to-one linkage between the social and environmental unit is given by definition. Social surveys that encompass demographic, social, and land-use characteristics can be linked directly to remotely sensed data to link landcover changes to the land-use practices. The situation is more complicated in Monroe County, where considerable parceling of the landholdings has taken place over time. Moreover the deforestation has been much more pronounced as compared to Altamira. In Monroe County household-level survey data have been linked to spatial digital form data. Even more complicated is the village settlement pattern in Nang Rong, where households are concentrated in the village center and agricultural fields are centered around the village. Households often cultivate multiple lands in different locations. A multi-level modeling approach that includes household and community variables has been applied for Nang Rong.

The difficulty of valuing environmental services introduces a normative dimension into P–E analysis and is addressed in the chapter by Vaclav Smil. The chapter starts by clarifying the complementarity of environmental goods (e.g., fossil fuels and timber) and environmental services (e.g., soil formation). Smil then introduces various definitions of environmental services noting the interdependence between environmental services themselves and their interdependence with living as well as nonliving organisms. To value environmental services is useless, as Smil suggests, since we cannot measure the contribution of environmental services. Smil explicitly declines to use notions such as the willingness to pay, which is most common in this literature. The main message is that we cannot value something when we are not aware of its multiple functions as they relate to us. By referring to the diverging results found in the studies of Costanza et al. (1997) and Pimentel et al. (1997), both of which aimed at attaching some value to the world's ecosystems, Smil presents the evidence that such estimates are at best useless and at worst distorting. The chapter concludes with two goals that should be followed: (a) leave most valuable ecosystems alone, and (b) limit environmental impacts that result from population growth and economic development.

The penultimate chapter in the volume, by Wolgang Lutz and colleagues, addresses one of the most difficult questions in P–E system modeling: the tradeoff between highly disaggregated and highly aggregated models. In this sense the chapter complements the other contributions that surveyed various methodological approaches but did not assess the advantages and disadvantages of these approaches. The underlying P–E system studied in Lutz et al. is the PEDA model that has recently been developed in collaboration with the United Nations Economic Commission for Africa to capture the interactions between population and the environment (land and water resources) in sub-Saharan Africa. Besides a detailed multi-state population model that provides projections of the population by age, sex, food security status, literacy, and rural/urban place of residence, the food distribution mechanism plays a key role in the final impact that the population will exert on the environment.

The first part of the chapter presents an application of the full PEDA model to Mali. Various alternative projection assumptions demonstrate the key role of education and subsequent fertility declines in improving food security and lessening the impact of population growth on the environment. The second part of the chapter is devoted to the reduced-form PEDA model, which essentially aggregates over education, age, and sex, focuses on the rural population, and considers food distribution as the key mechanism driving the model. The close resemblance between the scenario outcomes of the full and reduced-form PEDA model proves the importance of the intervening factor, that is, the food distribution mechanism, for the long-run development of the environment and population. The final part of the chapter discusses the complementarity between the two approaches.

The volume concludes with a chapter by Lutz, Sanderson, and Wils that presents a series of fully comprehensive P–E studies and ends by defining some criteria for future work in the field. While most of the contributions of this volume focus on one specific chain of causation in the P–E field (i.e., one sectoral slice in Figure 1 above) it is also useful and important to see the forest in addition to the trees. A series of comprehensive population–development–environment (PDE) case studies conducted by IIASA over the past decade was dedicated to gaining the most comprehensive picture possible about past, present, and likely future P–E challenges for a specific country or region using both qualitative methods and computer simulations. This contribution describes the general approach of this series of studies and highlights some important types of analyses and findings that could not be reached with a less comprehensive approach.

In the second part, the concluding chapter develops some methodological criteria and suggestions for future efforts in the field of P–E analysis. The main methodological point made there is that studies of interactions between P and E should also include the description of the inherent dynamics of both P and E. In other words, if someone wants to study the impact of population on, for example, water availability, it would be advisable not only to focus on specific mechanisms of causation but also to include an analysis of the population dynamics and the hydrological dynamics in an explicit way in order to more fully and adequately capture the interactions. It is stressed that although frequently explicit considerations of both the population and the environmental dynamics are left out of the analysis, there is often no good reason for doing so. Good models of these dynamics are readily available (the chapter describes an example of a multistate population model for this purpose) and the coherence and usefulness of specific P–E studies would gain from more explicit consideration of these P and E dynamics in addition to all the relevant mediating processes.

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