

Introduction

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Abstract

Social Ecology is inter- and transdisciplinary research field concerned with society–nature interactions. It integrates contributions from the Natural Sciences with those from the Social Sciences and Humanities to provide a scientific basis for sustainability. Socioecological research addresses spatial scales from the local to the global and is concerned with the past, present, and future. This chapter serves as an introduction to a volume that takes stock of 25 years of research at the Institute of Social Ecology in Vienna.

Keywords

Social ecology, Social metabolism, Colonization of natural processes, Socioecological transitions, Environmental history, Long-term socioecological research (LTSER)

Why Social Ecology?

Climate change, biodiversity loss, deforestation, the finiteness and the potential depletion of natural resources, poverty, hunger, and unequal access to necessities for livelihood, such as land, food, and energy, are among the plethora of challenges commonly included in the daunting agenda summarized by two magic words: ‘sustainable development,’ which some believe to be an oxymoron (Hall 2004). The concept of sustainable development can be traced to eighteenth century German forestry (Gottschlich and Friedrich 2014), where it denoted the imperative that the harvest of trees must not exceed their regrowth in the forest.

‘Sustainable development’ gained international prominence with the publication of the *World Conservation Strategy* (IUCN et al. 1980) and, in particular, with the report *Our Common Future*, issued by the World Commission on Environment and Development (WCED; United Nations 1987; see also Chap. 29). The concept was proposed in an effort to overcome the stalemate between those aiming to respect ecological ‘limits to growth’ (Meadows et al. 1972) and those seeing growth as imperative for developing countries to overcome poverty, hunger, and high infant mortality (World Bank 1978) or as the natural course of progress, as many Neoclassical economists see it (Rohlf 2008). The notion of sustainable development was successful. It promised the reconciliation of continued economic growth for an equitable and just development of the world’s poorer regions, or intragenerational justice, with intergenerational justice, or the imperative to keep the global resources and ecosystems as well as the climate system in a condition suitable for future human existence and prosperity (Fischer-Kowalski and Haberl 1997; Haberl et al. 2004). This reconciliation was expected to be achieved by ‘decoupling’ social and economic development from the use of biophysical resources and, ultimately, from environmental pressures and degradation (United Nations 1987; World Bank 1992).

The turn from the ‘limits to growth’ deadlock to a debate on how to reconcile development with environmental protection was a challenge for the scientific community. Viable solutions require collaboration across scientific disciplines—in other words, interdisciplinarity. They even require collaboration between scientists and stakeholders from different social groups, such as policy-makers, administration, business and industry, civil society, and many more—usually denoted today as ‘transdisciplinarity’ (Dressel et al. 2014). The call for inter- and transdisciplinary programs of ‘sustainability science’ emerged (e.g., Clark and Dickson 2003; Kates et al. 2001), and new interdisciplinary research fields, such as Ecological Economics (Martinez-Alier 1987), Industrial Ecology (Ayres and Simonis 1994), and Environmental History (McNeill 2000; Sieferle 2001), gained significance.

As Marina Fischer-Kowalski and Helga Weisz explain in Chap. 1, Social Ecology, as understood in the ‘Vienna School’ at the Institute of Social Ecology in Vienna, is one of the islands in the archipelago of scientific approaches situated amid the continents of the Social Sciences, the Humanities and the Natural Sciences. Initially, a small group of researchers designed environmental reports and indicators to make visible and quantifiable the roles of human agency, socio-economic contexts and institutions in altering the environment and placing ecosystems under pressure. The Institute of Social Ecology has since become a vibrant and larger but closely interacting group of scientists from the Social Sciences (in particular, Sociology and Anthropology), History and the Natural Sciences (in particular, Ecology), with the aim of forging an inter- and transdisciplinary research agenda.

Aims and Scope of this Volume

The scholarly literature on sustainability research is growing with the urgency of the issues. This book is the first comprehensive overview of Social Ecology that outlines its contributions to these scientific and societal challenges. It presents the current state of the art in Social Ecology, demonstrating the Vienna School's attempts to tackle global sustainability problems through innovative inter- and transdisciplinary scientific research. The core axioms of the Vienna School of Social Ecology are that social and natural systems interact, coevolve over time and have substantial impacts upon one another, with bidirectional causality. Social Ecology addresses energy and society, land use and food production, metabolism of societies, and the short- and long-term environmental impacts of human activities. It offers a conceptual approach to society–nature coevolution pertaining to history, to current development processes and to a future sustainability transition.

This book takes stock of Social Ecology and discusses its relation to neighboring fields and its epistemic and conceptual foundations. It introduces concepts and epistemological questions in a series of overview chapters. The strengths of socioecological research are highlighted by presenting inter- and transdisciplinary research on a variety of themes that touch upon all areas of the globe, covering spatial scales from urban and rural investigations to national and global analyses as well as temporal scales across past centuries and extending into the future. We introduce important socioecological methods in *Method Précis* attached to thematically related empirical chapters. This exemplification of current socioecological thinking is suitable for classroom use and extends the research frontier of Social Ecology in new and innovative directions. The book has been written by a diverse team of natural scientists, social scientists, and historians, building upon more than 25 years of shared experience.

The themes discussed include the following:

- Resource flows (materials and energy) and their measurement across time and space, the limits of these flows and their environmental and socioeconomic implications
- Relations between production and consumption as well as the role of trade in shaping the patterns and trajectories of resource use
- Land use and its relation to ecosystems and to socioeconomic material and energy flows
- The significance of urban development and city–hinterland relations and how they change over time
- Fundamental long-term changes in the relations between societies and their environment ('socioecological transitions') and the effects of these changes on land use and resource flows
- Connections among labor, gender relations, and energy and resource use
- Human pressures on biodiversity and ecosystems
- Climate change and drivers of greenhouse gas emissions in terms of resource flows and land use.

Socioecological approaches are interdisciplinary in nature. The applications are manifold, ranging from science to practice and from the local to the global. We discuss them throughout these chapters in their respective thematic contexts. Social Ecology aims to provide scientific foundations and to intervene, through stakeholder engagement, in various fields of discourse and policy to support sustainability. The book touches upon many pertinent issues, including the following:

- Spatial and temporal scales
- Long-term trajectories
- Historical legacies
- Future scenarios
- Energy transitions, both past and prospective
- Opportunities and limits of stakeholder involvement
- Complex systems thinking
- Sophisticated statistical data analysis across usually separate domains.

The process of creating this volume involved a stringent supervision by the editors and several workshops with all the authors—a process that lasted more than 3 years. Through this joint process, we were encouraged to develop socioecological theory further and to achieve common viewpoints while maintaining the richness of various scientific approaches and flavors. The book assembles a substantial amount of original material, and it differs from many edited volumes because of its high internal consistency. It builds upon and refers to many earlier efforts (such as Armitage et al. 2007; Becker and Jahn 2006; Berkes et al. 2003; Gunderson and Holling 2002). Recently, a number of books have appeared with a similar ambition to capture some of the essence of socioecological thinking (such as Allwood et al. 2012; Baccini and Brunner 2012; Giampietro et al. 2012; Glaser et al. 2012; González de Molina and Toledo 2014; Kander et al. 2013). We hope to match their achievements by the breadth of approaches offered, sustained by a large team disciplined in a long tradition of jointly developing and adhering to a shared theoretical paradigm and washed in the waters of many scientific traditions.

Box: Adventures in Social Ecology

Inter- and transdisciplinary research can result in challenging experiences due to the encounters with colleagues with different backgrounds and, hence, different fundamental concepts, languages, bodies of literature, and habits. Here, we present four experiences we found to be particularly enlightening—and entertaining. To maintain their flavor as personal narratives, we identify the respective authors and keep the text in the first-person singular.

Walk the Line—experienced by Martin Schmid

I was trained as a historian and archeologist and came in contact with Social Ecology as a young student in the mid-1990s. From the very beginning, my relationship with Social Ecology was highly ambivalent. Being a green—in every respect—student of History, I was fascinated by the theoretical explicitness of Social Ecology and by its emphasis on the materiality (not to say ‘naturalness’) of the world. Even more, I enjoyed the academic culture in the group that has now become the Institute of Social Ecology. I simply liked how teachers interacted with each other and with us, students. What a contrast to most of my experiences at the History Department of the University of Vienna, in intellectual as well as social terms. At the same time, I found social ecologists to be irritating, with their diagrams made up of circles and boxes, their databases filled with numbers, their talk of systems interacting with each other, and their strange Luhmannian idea of a society made up of communications. I had only been disciplined to view the world as a world of actors—humans, of course, driven by the motives that are highly variable over time and are culture dependent. But in the world of Social Ecology, there were no actors and no motives one could reveal using what historians call ‘source critique.’

One of my first papers turned that irritation into a product. I discussed and criticized the concept of ‘colonization of natural systems’ by using it as an Environmental History interpretation of an agricultural handbook from the sixteenth century. The result was a rather clumsy culturalist critique of Social Ecology, and in that sense, quite typical for a freshman with a background like mine. Nevertheless, the Institute was generous in publishing this piece as a Social Ecology Working Paper.

This story points to one of the most important qualities of Viennese Social Ecology. The institute has been successful in walking the thin line between developing and caring for a common conceptual ground on the one side and dealing with diversity on the other side, including internal diversity and the diversity of research fields in its academic neighborhood. Viennese Social Ecology was and (as proven by this book) is an intellectual environment where one can see what is needed to realize interdisciplinarity. This requires both openness to and curiosity for other, sometimes irritating, perspectives. But it also requires a clear theoretical standpoint. Fortunately, Social Ecology has such a clear standpoint, with a shared paradigm according to which social and natural systems interact and coevolve over time. From our diverse disciplinary backgrounds, we all know about the limitations of that paradigm. We know in which sense and under which (disciplinary) pre-decisions it is false. This is what makes it a source of scientific rigor.

Almost 20 years have passed since I made first contact with Social Ecology. Now I am engaged in Environmental History at the institute. Clearly, the institute has changed since then. Yet some things have not changed. It is still an intellectual pleasure for me to criticize the shared paradigm of Social Ecology from a historian's perspective and to search for conceptual alternatives such as 'socio-natural sites' (SNSs; Chaps. 6 and 23 in this volume; Winiwarter and Schmid 2008), alternatives that follow the overall aim of integrating the Natural and Social Sciences with the Humanities but are better suited to involve the latter in such an endeavor. Social Ecology has become an important part of my academic identity that allows me to talk at the *Deutscher Historikertag* (German Historians' Day) about how ignorant most historians are of nature and to talk to an audience of limnologists about natural scientists' ignorance of society and culture at a conference about the Danube. Sometimes, it happens that I find myself arguing for and defending Social Ecology against culturalist and solely actor-centered approaches.

As a Socioeconomist, What is Your Take on That?—experienced by Helmut Haberl

Several times, even repeatedly with the same colleagues, I have had the following experience. After discussing a biophysical phenomenon such as biodiversity loss or climate change with a group of several natural scientists, such as ecologists or meteorologists, they turn to me and ask, 'As a socioeconomist, what is your take on that?'

The irony of the story is twofold. First, I was trained as a biologist, earth scientist, and mathematician and have studied biophysical phenomena such as energy use, biomass flows, and carbon cycles throughout my scientific career. Although I have been working with social scientists, historians, and economists for decades, I have no formal training in the Social Sciences and Humanities and would never regard myself as a social scientist, historian, or economist. Second, of course, 'socioeconomics' is not a scientific discipline at all. Clearly, there is a plethora of Social Science disciplines as well as specializations in the Humanities, such as Sociology, Anthropology, Macroeconomics, Microeconomics, History, Philosophy, Pedagogy, and many more. No scholar from any of these disciplines would regard him- or herself as a 'socioeconomist'; this seems to be a species of scientists recognized more by natural scientists than by their own close colleagues.

Perhaps the issue is deeper. I suspect that those (honorable and well-intended) natural scientists who are motivated to link up with social scientists, economists or scholars from the Humanities often find it difficult to communicate with those strange creatures from remote continents—to take up the metaphor stressed by Fischer-Kowalski and Weisz in Chap. 1 (and vice versa, of course!). Several times in such encounters, my impression was

that these fine colleagues regard me as an ambassador of foreign and somehow uncanny territories who has the advantage of speaking their language and knowing their culture well enough to facilitate exchange. Thus, perhaps we Social Ecologists should take it as a sign of appreciation when we have similar experiences!

Have You Ever Read Hegel?—experienced by Robert Groß

Having successfully applied for a scholarship, I went to Aalborg University in spring 2013. A fellow Ph.D. student convinced me to present at a conference dealing with theory and empirical research in the Social Sciences and Humanities. All participants were cultural, intellectual or social historians, whereas I consider myself a human ecologist (with a Natural Science background) doing Environmental History. My paper addressed the concept of ‘socio-natural sites’ (SNSs), applied to the case study of Damüls/Vorarlberg (Chap. 23). The concept of SNSs is based on the assumption that social practices and material arrangements (e.g., landscapes) are structured by each other. If one or both changes, either by human hands or due to non-human influence (e.g., a shift in snowfall pattern), the SNS transforms (Chap. 6). The first question after I had delivered my paper left me dumbfounded for a moment: ‘Had you read Hegel before writing your paper? The transformation of an SNS corresponds with Hegelian Dialectics.’

What is the point of this story? According to Pierre Bourdieu, social relations among established disciplines, which are considered theoretically pure and more empirically and application-based areas of scholarship (such as the parvenu ‘interdisciplines’ Social Ecology and Environmental History), are never neutral. Rather, representatives of higher-rated disciplines (e.g., Philosophy) claim interpretational sovereignty by referring to their prophets of historiography (Bourdieu 1984). One could argue that my colleague used Hegel as a metaphor for doing pure, intellectual history. My point is that he considered the study of materiality as historical force to be heretical. It is obviously a sensitive issue in historiography.

What is the potential of the heresy, of the concept of SNSs when communicating with historians? To me it became evident when other conference colleagues presented their respective papers, using ‘practices’ to analyze series of pictures taken by immigrants to depict motifs linked to their concepts of home. Most of the pictures displayed material artifacts, but the researchers avoided the nexus between practices and objects. Thus, no one asked the presenter for his or her relation to the masterminds of Philosophy (e.g., Hegel); rather, the discussion was one-sided, narrowed to the cultural background (gender, age, race and nationality) of the photographer. My impression of this discussion is that of the heretic. To look at practices this

way means not to use the full analytical potential of praxeology and to sell old wine in new skins. The investigation of the transformation of practices and materiality—that is, the SNSs approach—bears the potential to structure narrations. Furthermore, the concept opens black boxes of communities, historiography and Social Ecology. From my point of view, the concept of SNSs is useful because it avoids dead-end discussions about what ‘nature’ and ‘culture’ mean, which have pervaded scholarship for much longer than Social Ecology and Environmental History have existed.

How Does This Fit?—experienced by Christoph Plutzer

Equipped with an extensive background in Natural Sciences (Biology, Geographic Information Systems), I began work at the Department of Vegetation Ecology at the University of Vienna in 1998. My job was to develop a map of avian species richness in Austria as part of a project within the Austrian ‘Cultural Landscapes’ research program and as a contribution to my Ph.D. project.

Soon after, the organizers of the ‘Cultural Landscapes’ program promoted a seminar entitled ‘Ecological Orientations,’ organized by the group known as the Viennese Institute of Social Ecology. My project leader encouraged me to participate in this course because of the Institute’s reputation within cultural landscape research, and he thought it would be helpful in developing contacts. Because I needed to take courses for my Ph.D. study anyway, I decided to join—without any idea what to expect.

The seminar lasted three days and took place at a nice venue far out in the Lower Austrian countryside. Marina Fischer-Kowalski and Verena Winiwarter were teaching approximately 20 students with very different backgrounds, and I was one of the few in that crowd who had never been exposed to Social Ecology. Retrospectively, I do not think I recognized the life-changing elements of this seminar then, but I remember realizing the advantages of the concepts that were discussed. Trained as a natural scientist, I perceived the unique socioecological concepts of nature and its interactions with society almost as a sacrilege—but on second thought, I recognized how important and helpful that integrated interdisciplinary approach was. I was excited about these revelations without anticipating that I was ever to become part of that Institute and contribute to this book in the remote future.

Later, I was pleased to collaborate in joint projects that allowed me to dig deeper into Social Ecology. Infected with concepts such as the Human Appropriation of Net Primary Production (Chap. 14), I was soon labeled a ‘socioeconomist’ in my traditional surroundings. Several times, I realized that someone expected some ‘socioeconomic’ input or expertise from my

side, which always resulted in disappointment on both sides. Questions like ‘socio – what?’ or ‘how does this fit?’ made me aware that an interdisciplinary approach was alien to most people, not to only researchers but also—and maybe especially—to non-scientists. I remember a couple of instances when someone, after having received an explanation of what I am doing, called out, ‘Wow, that’s really interesting!’ But to be honest, my interlocutors often did not show so much enthusiasm. I do not know why, but many people turn reticent when it comes to interdisciplinary research. A strange animal such as Social Ecology can occasionally even intensify this reserve.

In conclusion, my ‘socioecological adventure’ may have driven me away from my roots, but in exchange, I had the possibility to participate in the challenges and excitements of interdisciplinary socioecological work—an experience that has become an important part of my life.

The Organization of this Book

In an attempt to display the strengths of Social Ecology in its continuous cross-fertilization of conceptual interdisciplinary thinking and empirical research, we have organized this book into five parts. The first part is entitled *The Conceptual Repertoire*, the second part *Empirical Approaches to Socioeconomic Metabolism*, the third part *Empirical Approaches to Long-Term Socioecological Research*, the fourth part *Empirical Approaches to Land Use and Colonization of Ecosystems*, and the fifth part *Empirical Approaches to Working with Stakeholders*. Interspersed in the second part are so-called *Method Précis*, short, non-technical explanations of important socioecological methods. These are attached to appropriate chapters. If a method is used in several chapters, the *Precis* is attached to the chapter where it first plays a substantial role. At the end, we supply an outlook section.

Part I—The Conceptual Repertoire

Chapter 1 opens the set of conceptual pieces by drawing a map of the ocean separating the three continents reigned over by the Natural Sciences, the Social Sciences and the Humanities. On that map, Marina Fischer-Kowalski and Helga Weisz identify the Social Ecology archipelago and, within that, the Viennese School of Social Ecology, among other interdisciplinary research fields. They portray Social Ecology as centered on a shared paradigm according to which human social and natural systems interact, coevolve over time and have substantial impacts upon one another, with causality pointing in both directions. Social Ecology addresses energy and society, land use and food production, the metabolism of societies and the environmental impacts of human activities. It offers a conceptual approach to society–nature coevolution pertaining to history, current development processes and a future sustainability transition.

Chapter 2 follows suit with an in-depth discussion of the conceptual and methodological repertoire of the Viennese Social Ecology. In this contribution, Marina Fischer-Kowalski and Karl-Heinz Erb outline the concepts of socioeconomic metabolism and the colonization of nature and discuss their epistemological foundations. Socioeconomic metabolism refers to material, substance and energy flows related to socioeconomic activities. The colonization of nature denotes purposive interventions into natural systems aimed at improving their utility for societal purposes. The chapter poses questions such as the following: can we conceive of social systems as ‘hybrid systems,’ a structural coupling between communication systems (in the tradition of sociological systems theory) and biophysical elements such as a human population, infrastructure and animal livestock? Is such a conceptualization consistent with notions of biological and cultural evolution and with complex systems theory?

The metabolism of human societies underwent major changes during the course of human history and is in a transition process now, as discussed in depth in Chap. 3 by Fridolin Krausmann and colleagues. Since the time of Paleolithic hunter-gatherers, the amount of materials extracted and used by humans and their impact on their environment has grown by several orders of magnitude. The chapter recalls major stages in human history through the lens of societal use of materials and energy. It introduces the notion of sociometabolic regimes and discusses the characteristics of resource use in hunter-gatherer societies, agrarian societies and the emergence of the industrial metabolic regime. It then discusses the variability within and among those regimes and the related environmental and sustainability problems.

Land use is a prime example of the human colonization of natural systems, as shown by Karl-Heinz Erb and colleagues in Chap. 4. Land use involves the colonization of ecosystems, organisms and, increasingly, the genomes of crop plants. This text focuses on land-use intensity, an important but far under-researched aspect of land use. It shows how the core concepts of Social Ecology—socioeconomic metabolism and the colonization of nature—open innovative avenues to research on land-use intensity. The authors argue that the strengths of the socioecological method inventory include the strict application of first principles, a sound and meaningful system boundary between society and nature and the accessibility for Social as well as Natural Science approaches. These features are seen as prerequisites for guiding data collation and organization, which allow researchers to investigate the feedback cycles between social and natural systems that constitute the trade-offs and synergies of the land system.

As apparent in several narratives in the box *Adventures in Social Ecology*, the tension between actor-centered and systems approaches represents an intellectual powerhouse of Social Ecology. In Chap. 5, Daniel Hausknost and colleagues tackle this conundrum head on. Their vantage point is that the emphasis on systems in many socioecological studies can profit from a complementary focus on actors in empirical socioecological research. Actors and their agency play an important role in transdisciplinary research, in local studies and in Environmental History. How do these actor-centered areas of research connect to

the systems-centered theoretical framework of Social Ecology? How is agency accommodated in systems, and how can systems and their structures be influenced by actors? This chapter explores these questions both theoretically and in relation to concrete research examples. In doing so, it highlights some of the unresolved theoretical questions in Social Ecology and points toward possible ways they can be resolved.

In attempting to understand long-term changes, Social Ecology has employed a variety of different perspectives. One that has proven useful in many contexts is the concept of legacies, as Verena Winiwarter and colleagues discuss in Chap. 6. What one can learn from looking at things in a long-term comparative approach is exemplified by the ‘fossil-energy-powered carbon sink’ in Austria’s agrarian–industrial transition and by the case of colonial mercury and silver mining in Central and South America. The importance of long-term legacies for the course of human history as well as our current predicament becomes visible, demonstrating the strength of an interdisciplinary socioecological approach to better understand current sustainability issues.

Labor is a central category in many Social Sciences, and it is central in Social Ecology because the process of colonization consists of physical interventions into Nature and requires human labor. In Chap. 7, Marina Fischer-Kowalski and Willi Haas outline a socioecological concept of labor. Throughout human history, socioecological transitions strongly affected human labor. The previous transition into the prevailing fossil-fuel-based sociometabolic regime fundamentally changed labor’s characteristics in terms of physical power, knowledge and empathy. Lifetime spent on labor was reduced, and a new form of institutional organization became dominant: wage labor. Consequently, these authors ask how a transition away from the use of fossil fuels will shape labor’s future.

Part II—Empirical Approaches to Socioeconomic Metabolism

The growing size and changing structure of socioeconomic metabolism is a major cause of the sustainability problems humanity is facing at the beginning of the twenty-first century (Ayres and Simonis 1994; Baccini and Brunner 2012; González de Molina and Toledo 2014). Socioeconomic metabolism is a core concept of Social Ecology. During the last two decades, the Vienna team has made important contributions to the advancement of the concept. It has developed related methods, and it has conducted a large number of empirical studies. This part of the book assembles contributions analyzing patterns and trends of socioeconomic metabolism and their drivers from global to national economies and across different temporal scales.

In the first contribution to this section, Fridolin Krausmann and colleagues (Chap. 8) investigate the evolution of global material and energy use since the take-off of global industrialization in the mid-nineteenth century. They show that global resource use has grown by more than an order of magnitude, much faster than population but slower than gross domestic product (GDP). They find that after a slow-down of global growth related to the stabilization of resource use at a high level in industrial countries, growth accelerated in the last decade, driven by

emerging economies. This work reveals the full dimension of the metabolic transition and its impact on the extraction, trade and use of materials and energy at the planetary scale. Completing this historical transition globally may well be physically impossible due to resource constraints, but even if it were possible, it would wreak havoc with the earth's biotic and climatic systems.

In Chap. 9, Andreas Mayer and colleagues take a closer look at the variability of patterns of material consumption across individual countries. Their analysis of material flows in 180 countries shows that large differences in material flows can prevail even within groups of countries with a similar level of industrialization and economic development. The authors identify four major factors underlying the differences in global patterns of national material flows: resource availability, trade, population and GDP. The text highlights the potentials and limitations of indicators for direct material flows. These indicators provide important information about the material use patterns resulting from the domestic production structures, but they fail to adequately reflect the significance of final consumption.

Anke Schaffartzik and colleagues (Chap. 10) take up this point and address an issue that has recently received much attention in material flow studies: growing trade volumes and the deeper integration of all economies into global markets have posed a new challenge to material flow accounting (MFA). Addressing this challenge requires methods and approaches that expand MFA from a production-centered perspective to one that targets the resource flows related to consumption. The text critically discusses recent methodological developments in the field and, in its empirical part, shows how the shift to a consumption-based approach changes the material flow accounts for the Austrian economy.

The idea of a Circular Economy has become a prominent notion in the political discourse about sustainable resource use. Industry and governments in both industrial and emerging economies like to promote the term. In Chap. 11, Willi Haas and colleagues apply a sociometabolic approach to assess the degree of circularity of the global economy. Their analysis shows that only 7 % of all materials entering the global economy in 2005 were recycled. They identify the high share of materials used to generate thermal energy and the large and growing amount of materials accumulating in stocks as major obstacles to closing material loops, and they discuss the most effective steps toward a Circular Economy.

In Chap. 12, Dominik Wiedenhofer and colleagues investigate the role material stocks play in resource use patterns and sustainable development. Building and maintaining stocks of buildings and infrastructure is a major driver of resource use in both emerging and industrial economies, and large amounts of materials accumulate in growing stocks. The chapter presents an estimate of biophysical stocks of nonmetallic construction materials in residential buildings, roads and railways in the EU25, as well as related material input and output flows. Using a scenario approach, the authors assess stock-related material flows and recycling potentials for 2020. They identify proper management of existing transportation networks and residential buildings and a deceleration of the ongoing stock expansion as important steps toward more sustainable resource use.

Part III—Empirical Approaches to Land Use and Colonization of Ecosystems

Land use has transformed the face of the earth (Thomas et al. 1956; Turner et al. 1990) and is recognized as a pervasive driver of global environmental change (Foley et al. 2005). Since its inception, socioecological research has been concerned with land use, generating innovative concepts and avenues for empirical research as it progressed. This part of the book opens with a contribution by Karl-Heinz Erb and colleagues (Chap. 13), who discuss the role of livestock grazing, ‘the neglected land use.’ The observations are impressive: livestock consumes approximately 60 % of all the biomass used globally for human purposes (Krausmann et al. 2008), and livestock grazes approximately 36 % of the earth’s lands, an area that is considerably larger than any other land-use category (Erb et al. 2007). The chapter discusses how socioecological methods can help tackle the conundrum of how to better understand the important process of livestock grazing in the earth system.

In Chap. 14, Helmut Haberl and colleagues discuss how socioecological methods—above all, the concept of ‘human appropriation of net primary production,’ or HANPP—can help researchers explore systemic feedbacks in global land use. The authors argue that a biophysical approach capable of linking land-use maps with biomass flows can help researchers understand how changes in one land use affect the entire system. Such changes create feedback that may cause havoc in unexpected places—for example, when the implementation of biofuels drives up food prices (Coelho et al. 2012) or when ‘indirect land-use change’ results in greenhouse gas emissions that may, in some cases, render biologically produced energy more destructive to the climate than fossil fuels (Chum et al. 2012).

Anthropogenic vegetation fires are another aspect of the global land system a socioecological approach can address. As Christian Lauk and Karl-Heinz Erb show in Chap. 15, human-induced vegetation fires play a central role in past and present society–nature interactions. There is evidence that tens of thousands of years ago, hunter-gatherers were already employing fires as a hunting technique. Today, vegetation fires continue to be an integral part of shifting cultivation and traditional pastoralism, and they are a crucial tool for the clearing of forests. At the same time, vegetation fires represent a risk that threatens infrastructures and contributes to climate change and air pollution. This text convincingly demonstrates how socioecological thinking can contribute to analyzing to what extent and under which circumstances human-induced vegetation fires are sustainable.

International trade plays an increasingly important role in supplying societies with biophysical resources and products, and land-based products such as food, feed, fiber and bioenergy are no exception. In Chap. 16, Helmut Haberl and colleagues show how extending the HANPP approach can lead to the consumption-based concept of ‘embodied HANPP’ to analyze teleconnections related to global biomass trade. Using the European Union as an example, they discuss how embodied HANPP can be estimated using bilateral trade matrices of biomass-based products. They show that the EU27 increasingly depends on lands outside its territory, and they discuss what that implies in terms of the land-related policies of the European Union.

Just as livestock grazing may be a neglected land use, Africa seems to be the neglected continent in terms of regional research efforts. Maria Niedertscheider and colleagues (Chap. 17) address that gap by using HANPP to analyze changes in Africa's land systems. They show that African land-use systems are unique compared to other world regions, with land-use intensity being lower than on any other continent. They analyze the current stage and main determinants of African land systems and their changes since 1980. Biomass harvest increased markedly in Africa, but this increase was driven mainly by cropland expansion rather than yield increases, which were more important almost everywhere else. Consequently, harvest growth was associated with considerable increases in the human domination of ecosystems in Africa.

Biodiversity is an important aspect of earth's ecosystems as it is related to the provision of goods and services that are essential to human society. In Chap. 18, Christoph Plutzer and colleagues discuss concepts and causes of biological diversity and—based on the socioecological interaction model—the relationship between human societies and biodiversity. Using empirical examples from Austria, they show how HANPP helps researchers study pressures on biodiversity related to changes in land use and its intensity. The results underline the potential of socioecological indicators to facilitate analysis of the interrelations between biodiversity and society.

Part IV—Empirical Approaches to Long-Term Socioecological Research

It has long been clear to ecologists that a systemic understanding of ecological systems requires long-term observations. Over the course of the twentieth century, Long-Term Ecological Research (LTER) at designated sites was established, albeit mostly in 'pristine' areas with as little human 'disturbance' as possible. Later, with the insight that most of the earth's land cover is influenced by humans and that the study of human-influenced land is badly needed, even urban LTER sites were set up. LTSER, Long-Term Socioecological Research, does more: it integrates the study of social systems and ecosystems at nested spatial levels over time to elucidate their interaction (Redman et al. 2004; Singh et al. 2013). The chapters in this section apply socioecological concepts and methods to historical case studies and illustrate their potential for LTSER and Environmental History. The chapters span a broad range in terms of both approaches and topics addressed, thereby showcasing the added value that can be gained from combining different scientific disciplines in long-term studies.

Martin Schmid, in Chap. 19, reconstructs the dramatic transformation of a peculiar landscape, the Donaumoos, a wetland along the left bank of the Upper Danube in Bavaria that was systematically drained from the 1770s onward. Drainage started during the first phase of the transition from an agrarian to an industrialized sociometabolic regime. The environmental and social consequences of this project were heavily contested already among contemporaries. With a long-term perspective covering more than 250 years, this Environmental History of the Donaumoos exemplifies how societies are trapped in a 'risk spiral,' meaning that solving one problem always results in new risks. Experts in the eighteenth century

discussed major interventions into ‘natural’ systems with great passion. By revisiting a discourse of experts in the age of enlightenment, this chapter also contributes to a historical reflection of the term and the idea of ‘colonization of nature.’

Chapter 20, on Austrian carbon budgets from 1830 to 2010, is written by an interdisciplinary team. Simone Gingrich and her co-authors offer an explanation of the ‘forest transition,’ the somewhat paradoxical fact that forests regrow with industrialization in many parts of the world. Empirical evidence on Austria’s carbon budget in the period 1830–2010 shows that forests grew not only in area but also in wood density, resulting in the accumulation of ca. 240 MtC (megatons of carbon, 23 % of the initial stock) over the period. At the same time, society used more carbon, mostly in the form of fossil fuel. Austrian society amassed socioeconomic carbon stocks—in total, approximately 110 MtC—throughout the period, with construction wood being the main component. Annual carbon sequestration rates were well below fossil fuel emissions to the atmosphere. The authors conclude that the carbon sink in Austria’s ecosystems and society was mainly a by-product of increased fossil-fuel use that accompanied industrialization. This has important consequences for environmental policy because it suggests that carbon sequestration cannot be expected to play a major role in transitions toward a low-carbon society.

Traditional low-input agriculture had to organize local land, labor and livestock resources in a way that maintained soil fertility and stable yields, albeit at a low level. Industrialization transformed the socioecological functioning of agriculture and its role in socioeconomic metabolism. In Chap. 21, Fridolin Krausmann discusses Austrian farming systems and offers a sociometabolic perspective on changes in the colonization of nature. Industrialization turned agriculture into a high input/high output system producing high yields but consuming more energy than it produces. By formalizing the functional interrelations of agricultural systems into a sociometabolic model, it becomes possible to reconstruct this process of transformation for the case of Austria.

Whereas Austria is a typical case for the industrialized part of the world, the Philippines serve as a case study of land-use transitions and sociometabolic regimes in the developing world. In Chap. 22, Thomas Kastner and colleagues reconstruct the rapid land-use transition of the archipelago during the twentieth century. Forest cover decreased from approximately 70 % in 1900 to less than 25 % in 2000, while cropland areas and grasslands expanded. Land-use change is linked to the transition from an agrarian to an industrial sociometabolic regime. During the twentieth century, population density rose more than tenfold. Fundamental changes in the nation’s agricultural system ensued. During the first part of the century, food supply was maintained by expanding cultivated areas, while intensification became the dominant strategy thereafter. Fossil energy resources played a crucial role in this process. Massive changes in land-use intensity led to negative environmental impacts and increased dependency on fossil fuels and mineral resources. The Philippines are still in the midst of the transition toward an industrial society. The option space for future development is markedly smaller today than it was for those nations that pioneered the agrarian–industrial transition.

How tourism transformed an Alpine valley is the story Robert Groß tells in Chap. 23. Tourism moves global flows of capital, people and knowledge and thereby fundamentally transforms materiality, social relations, communities and life-worlds. This paper addresses the Environmental History of the alpine community of Damüls in Austria under the influence of tourism in the twentieth century. Environmental History seeks to understand historical society–nature relations and people’s perception of nature in the past. Such a project poses a twofold challenge for environmental historians. They need to conceptualize nature as an independent historical factor without reducing it to a social construct, but at the same time, they need to address the social construction of ‘beautiful landscapes’ as an integral part of the tourism industry. These viewpoints can only be bridged dialectically, and this chapter uses the concept of socio-natural sites (SNSs, see Chap. 6 in this volume; Winiwarter and Schmid 2008) to tackle that conundrum. The example of Damüls is a telling example of the restless transformation, supported by the post-World War II Marshall Plan, of an Alpine sport arena built for the sake of skiers.

The agrarian–industrial transition plays out in specific ways in urban areas. In Chap. 24, Sylvia Gierlinger and Michael Neundlinger present an urban case elucidating the output side of social metabolism by discussing the cleaning of a metropolis, namely, nineteenth century Vienna and, in particular, its sewage system. The rapid transformation of the city posed a veritable challenge for the existing disposal infrastructure. City officials responded in particular ways to these challenges. Vienna’s sewage system was built by incorporating many small creeks, thereby creating long-lasting legacies for river-city relations.

Part V—Empirical Approaches to Working with Stakeholders

Socioecological research aims to improve our understanding of transition processes and to support ongoing transition processes toward a more sustainable society. These chapters show how the approaches, concepts and methods discussed in the previous sections can bear fruit when applied together with stakeholders in practical settings, that is, in transdisciplinary projects.

Chapter 25, written by Veronika Gaube and colleagues, deals with the interaction of top-down and bottom-up decision-making determining the energy use in a city. Urban planning has to address a changing urban population and to provide the infrastructure required for the population’s socioeconomic and environmental living conditions. Households play a major role: they are affected by urban planning decisions and are co-responsible for the environmental performance of a city. This chapter presents an agent-based decision model for the city of Vienna. The model assesses spatial patterns of energy use by household types. It shows that changes in preferences related to green areas in the vicinity of living quarters strongly influence the spatial distribution of households within the city area. The model also analyzes how the distribution of different households strongly affects the spatial patterns of energy use.

In Chap. 26, Barbara Smetschka and colleagues discuss how the analysis of time use can enrich socioecological research. They present two case studies of Austrian rural areas characterized by small-scale farming. Time use is crucial for decisions on the production strategies of farms; farmers avoid longer working

hours as much as they try to maintain their income. The authors show that small-scale farming with a mixed production and cultivation of landscapes tends to increase the workload, particularly for women in a traditionally gendered working environment. Two alternatives are frequently chosen: farmers may either adopt less-sustainable methods of production or stop farming altogether. A better option may be to produce for the growing market for sustainable products with a new work organization that is attractive to young people and does not place a higher burden on female than male farmers. This presupposes (and can help finance) a local and regional infrastructure with care facilities. It also requires an innovative organization of labor and a fair distribution of the workload between sexes. Finally, it allows more leisure time for young farmers, men and women alike.

How does the 'local' relate to the 'global' and vice versa? Chap. 27, by Simron J. Singh and Willi Haas, illustrates this complex scale interaction, drawing on a case study from the remote Nicobar Islands in India. These islands, home to a rich tropical biodiversity and indigenous cultures, were subject to devastation by the 2004 tsunami. The tsunami took thousands of lives, devastated the villages, livestock and material culture and uprooted most of the coconut trees, a key base of subsistence. The overwhelming international aid that followed undercut the local self-determination of the islanders and resulted in a strong reliance on markets and cash flows. It led to surging material and energy flows dependent on aid and to fundamental changes in society–nature interactions. The new metabolic profile has high potential to drive large-scale land-use change and negatively affect local ecosystems. It remains to be seen how the Nicobarese, now without aid, will be able to recover not only from the first tsunami but also from the second tsunami of aid that washed away their modes of life that had been so well adjusted to their natural environment.

Chapter 28, on island sustainability, draws on several years of research and social involvement on the Greek island of Samothraki. Panos Petridis and Marina Fischer-Kowalski outline the challenges and the synergies of simultaneously conducting research 'on' a sustainability transition and research 'for' a sustainability transition. They explore the factors that cause island societies to prosper and sustain themselves and those that lead to collapse. In the past, a number of historical collapses, in the sense of breakdown of complexity and rapid population decline (Tainter 1990), have occurred on Samothraki. Currently, there is a fragile situation of slow decline of the population and rising ecological challenges, related mainly to excessive goat herding and tourism, that might lead to another 'tipping point' in the wake of the Greek economic and governance crisis and climate change. Meanwhile, the island community has decided to make an effort at turning the whole island into a Man and the Biosphere (MAB) Reserve according to UNESCO standards. Building upon a sociometabolic understanding of socioecological systems and using systems thinking and modeling efforts, the authors identify environmental and social tipping points for Samothraki intended to support that move. In line with the LTSER tradition, they argue that analyzing society–environment relations for different phases of the island's history and insights from past collapses can help to identify threats and possible ailments. Finally, this chapter reflects on both the process and the outcome of conducting transdisciplinary research.

Chapter 29, by Ulli Weisz and Willi Haas, reflects on the interrelations between two important societal concerns: sustainable development and health. This field of research underpins the key notion of ‘health co-benefits.’ The search for co-benefits aims to utilize synergies between both concerns, particularly between climate-change mitigation and health gains. It intends to inform policies in both arenas and to inspire collaboration. Although cross-cutting issues such as energy, agro-food systems and transport receive increasing international recognition, the health care system has rarely been addressed. The health care system takes responsibility for the reproduction of human health, usually through highly energy- and material-intensive forms of therapy. The health care system hence contributes to environmental problems and thereby contributes to health threats. In a transdisciplinary series of hospital projects involving scientists and health care practitioners, the authors ask how sustainability could be conceptualized for hospitals in line with both a socioecological understanding of sustainable development and with the ‘hospitals’ reality.’ The approach aims to avoid unintended long-term side effects of health care—hospitals’ core business—by expanding quality criteria for decision-making to include sustainability. The results of the testing phase convinced political actors in the health care system to make changes in their therapeutical settings. The authors demonstrate that ‘health co-benefits’ are a valuable argument within the sustainability debate.

Outlook and Conclusions

A recent compilation of global change indicators (Steffen et al. 2015) suggests that the Great Acceleration of human activities on earth—and the related pressures on its biophysical systems—is ongoing. There are no signs of humanity achieving any reductions in greenhouse gas emissions; on the contrary, they are continuing to grow, and faster than expected (Le Quéré et al. 2014). No comprehensive indicators exist to reliably monitor the global biodiversity trend (Jones et al. 2011), but there is little to suggest that biodiversity loss is slowing. Evidence is mounting that extinctions are already altering key processes that affect the productivity and functioning of ecosystems worldwide (Hooper et al. 2012). Recent research suggests that the world is running into constraints of resource extraction for several important resources simultaneously (Seppelt et al. 2014), thereby fueling a ‘peak everything’ debate. All of this is aggravated by financial crises in the world’s industrial centers, particularly affecting the US, Europe and Japan. Moreover, there are mounting concerns over growing inequalities in the distribution of incomes and wealth (Piketty 2014).

Sustainable development may hence be expected to remain high on the agenda, and with it the challenges of inter- and transdisciplinary knowledge production, or the ‘co-production of knowledge,’ as it has recently been termed (Mauser et al. 2013). This book summarizes the contributions Social Ecology can offer to both Science and practice. It aspires to bridge the Social Sciences with the Natural Sciences and

the Humanities to analyze society–nature interactions in a manner that is useful in designing interventions in Science and society:

- In relation to the Social Sciences, it aims to overcome the blindness of the Social Sciences to biophysical processes, enabling the Social Sciences to engage in sustainability discourses often dominated by the Natural Sciences and, in so doing, improving the ability to communicate with the Natural Sciences and the Humanities.
- In relation to the Natural Sciences, it aims to improve the ability to communicate with the Social Sciences and the Humanities, developing concepts for empirical research that link to social and cultural phenomena and overcoming arrogance and negligence vis-à-vis other realms of scholarship.
- In relation to the Humanities, it aims to improve the ability to communicate with the Natural and Social Sciences, to establish links with system approaches and to accept the role of natural phenomena in shaping the course of history.

This book shows both the conceptual depth and the empirical richness this agenda has fostered at the Institute of Social Ecology over the last few decades. It is based on the sustained effort of a group of researchers from various fields who have grappled with several problems, including the following: intricate conceptual issues; huge databases and data gaps; fundamentally different models, bodies of literature and academic cultures; and language disparities among the scientific ‘continents.’ This group has also striven to maintain productive and enjoyable working relations within a growing team. Finally, this group has addressed challenges in raising sufficient money to make all the above happen. We are enormously grateful for friendly support from colleagues, partners in practice and many other people and institutions. We are also grateful for the funding we have received from a great number of sponsors and funding agencies. There are too many supporters to list here, but most chapters thank them in their respective acknowledgement sections. We hope that you, the readers, will profit from this work. We would be truly grateful for your feedback. One person truly deserves to be singled out here, however. Elise Harder accompanied us as editorial assistant throughout the whole book writing and production process. Without her help this book would not exist. Thank you so much, Elise!

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