Chapter 1
The Archipelago of Social Ecology and the Island of the Vienna School

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Abstract Social Ecology is an interdisciplinary research field rooted in the traditions of both the Social Sciences and Natural Sciences. The common denominator of this research field is not a shared label but a shared paradigm. Related labels that extend beyond Social Ecology include Human Ecology, Industrial Ecology, Ecological Economics and Socioecological Systems Analysis. The core axioms of the shared paradigm are that human social and natural systems interact, coevolve over time and have substantial impacts upon one another, with causality working in both directions. Social Ecology offers a conceptual approach to society-nature coevolution pertaining to history, to current development processes and to a future sustainability transition. This chapter reviews several academic traditions that have contributed to the emergence of this paradigm and then describes the research areas belonging to the field. One cluster deals with society's biophysical structures (such as energy and society, land use and food production and social metabolism, the field covered by Industrial Ecology and Ecological Economics). Other clusters identify the environmental impacts of human societies (such as the IPAT and footprint approaches), biohistory and society-nature coevolution. Another research area considers regulation, governance and sustainability transitions. In the last section, we describe the distinguishing characteristics of the Vienna Social Ecology School.

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H. Haberl et al. (eds.), *Social Ecology*, Human-Environment Interactions 5,
DOI 10.1007/978-3-319-33326-7_1

Keywords Industrial ecology · Human ecology · Ecological economics · Social metabolism · Land use · Food systems · Sustainability transition · Society-nature coevolution · Energy and society · Natural resource use · Development · Environmental-impacts · Ecological footprint · Social-ecological systems

1.1 Introduction

We use the metaphor of an archipelago to describe Social Ecology as situated between the mainland of the Natural Sciences and Engineering on the one side and the mainland of the Social Sciences and the Humanities on the other side. Some islands are large and even have their own shipping lines (i.e., scientific journals), others are small and need to use foreign bypassing ships, and some are populated by isolated tribes. The populations on the archipelago are of mixed disciplinary origin and speak different scientific languages. They do not necessarily share a common name. They do share a few important features, however. They look at natural and social systems as systems in their own right that interact with one another, they believe causality between these systems works in both directions, and they search for less destructive and more sustainable ways in which the two systems can interact.

Social Ecology draws on traditions from several scientific disciplines (see Sect. 1.2) from the Social and Natural Sciences. Whatever the discipline of origin, the common motive for moving in the direction of socioecological research is a critical attitude toward the outcome of decades of differentiation and specialization among the academic disciplines (Latour 1991). The lack of intellectual cooperation, particularly from the 1970s onward, is considered detrimental to society's ability to properly understand and address its relation to the—increasingly strained—natural environment.

The common denominator of this research field is not so much a shared label—names extend beyond Social Ecology to Human Ecology, Industrial Ecology, Ecological Economics and Socioecological Systems Analysis—but a shared paradigm. The core axioms in this paradigm are that human social and natural systems interact, coevolve over time and have substantial impacts upon one another. What follows from this paradigm is a need to develop concepts and methods that allow us to address social and natural structures and processes on an equal epistemological footing. In various strands of the research, this challenge has been and is being resolved in different ways and at different levels of depth and consistency.

In the following essay, we will first reconstruct some of the earlier academic roots of social ecological thinking and then discuss several research traditions that address the biophysical features of human societies, such as energy, land use and social metabolism. Then, we will review approaches to identifying the environmental impacts of human activities. A third part is devoted to biohistory, and it reviews theoretical and empirical efforts to analyze the society-nature coevolution.

Finally, we will turn toward issues of regulation and governance, focusing on what to address as part of a sustainability transition. The last section characterizes the specifics of the Vienna Social Ecology approach.

1.2 Academic Traditions Contributing to the Emergence of Social Ecology

The academic roots of Social Ecology can be traced as far back as the 19th century, when the Natural and Social Sciences had not yet fallen into their respective epistemic boxes, which made later disciplinary crossovers so difficult. There are excellent reviews reconstructing such roots in the political economies of Adam Smith, David Ricardo, Karl Marx and Thomas Malthus (Fischer-Kowalski 1998; Martinez-Alier 1987; Sieferle 1990). These reviews illustrate the debates on the interrelations among population, land, food, technology and economic development. Whereas Smith, Ricardo and Malthus insisted on natural limitations for economic growth (in particular, land), Marx was the first to claim technological development (and thus human ingenuity) as the key driver of economic growth, thus overcoming natural limitations.

Another influential field was geography. George Perkins Marsh's book *Man and Nature: or, Physical Geography as Modified by Human Action* (1864) inspired at least two major efforts to comprehensively account for human-induced changes in the Earth system. One was the Princeton Conference on *Man's Role in Changing the Face of the Earth* (Thomas 1956). Another was the conference *The Earth as Transformed by Human Action*, held in 1987 at Clark University (Turner et al. 1990). In 1969, the German geographer Neef explicitly talked about the 'metabolism between society and nature' as a core problem of geography (Neef 1969). Since then, geographers have played a major role in Social Ecology.

Cultural Ecology, as brilliantly reviewed by Orlove (1980), is another important predecessor of later socioecological research. The beginnings of Cultural Anthropology (as in the works of Morgan 1877/1963) were, like Sociology, marked by evolutionism, that is, the idea of universal historical progress from more 'natural' and barbaric to more advanced and civilized social conditions. Then, Cultural Anthropology split into a more functionalist and a more culturalist tradition. The functionalist line retained a focus on the society-nature interface. Leslie White, one of the most prominent anthropologists of his generation and an early representative of the functionalist tradition, rekindled interest in energetics. White described the vast differences in the types of extant societies as social evolution, and the mechanisms propelling it were energy and technology (White 1943). Julian Steward's 'method of cultural ecology' considered the quality, quantity and distribution of resources within the environment. His approach can be illustrated by the early comparative study *Tappers and Trappers* (Murphy and Steward 1955), where two cases of cultural (and economic) change are presented in which tribes traditionally living from subsistence hunting and gathering (and some horticulture) completely change their ways of living because of their changing metabolism. The authors analyze this dynamic as an irreversible shift from a subsistence economy to dependence upon trade.

Despite some early calls for an 'ecology of man' (Adams 1935; Darling 1956; Sears 1953), Biological Ecology was reluctant to engage in Human Ecology before the environmental debate of the 1970s (Young 1974). Moreover, when the first influential texts by biological ecologists on Human Ecology finally appeared (e.g., Ehrlich and Ehrlich 1970; Ehrlich et al. 1973), they took a route that remained typical of most work by biological ecologists in this field until only recently: that of humans as agents of disturbance in ecosystems. This conceptualization of societies as one aggregated universal actor ignores the internal complexity unique to social systems and generates the misleading idea that society can be viewed as analogous to a single rational person. In addition, the exclusive focus on humans changing the environment prevented an understanding of mutual influences between society and nature. Together, these biases created severe barriers to interdisciplinary approaches toward the society-nature interaction. That ecologists tended to favor 'natural' ecosystems over 'human-dominated' ones as study objects may have contributed to these biases, but the most important factor was probably that many biological ecologists simply did not recognize the need to develop a more complex approach that would require conceptualizing socioeconomic systems as entities of a different kind than natural systems. Many ecologists may have been reluctant to engage in interdisciplinary cooperation. Even worse, neo-Malthusian concepts played an important role in the bioecological approaches toward Human Ecology (above all in the work of Paul Ehrlich), a point that hampered cooperation with social scientists. This changed substantially during the revived environmental debates of the 1970s, when major international research programs, such as *Man and the Biosphere* (MAB) by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the *International Human Dimensions Programme on Global Environmental Change* (IHDP), were launched, stimulating and supporting interdisciplinary work across the 'great divide' (Snow 1956) of the Social and Natural Sciences.

Meanwhile, the historical sciences, particularly the tradition of the Annales-School (Fernand Braudel), paved a path toward social ecological reasoning. For example, Braudel viewed the history of the Mediterranean as an outcome of interaction between social and natural processes. M. Godelier went further in formulating his core hypothesis in the introduction to *The Mental and the Material*: 'Human beings have a history because they transform nature. It is indeed this capacity which defines them as human. Of all the forces which set them in movement and prompt them to invent new forms of society, the most profound is their ability to transform their relations with nature by transforming nature itself' (Godelier 1984, p. 1). This way of looking at history is related to the Marxist tradition, but it transcends this tradition by moving in an ecological or coevolutionary direction. The classic reading of Marx leads to a discussion of changing 'modes of appropriation of nature' through the development of new means of production, that is, technology. Godelier's reading stresses the fact that human appropriation of nature modifies nature, and this modified nature in turn stimulates social change. Godelier thus deviates from typical Social Science by viewing nature as historically variable, not as static, and his core hypothesis attributes societies' historical dynamics to a feedback process from nature. The study of Environmental History since the 1970s is increasingly working along this basic idea of mutuality of nature-society relations (Winiwarter and Knoll 2007).

For Sociology, some claim the so-called Chicago School of Human Ecology (Park, Burgess, Duncan) as an entry point to the modern reading of Social Ecology. This school used analogues from biological ecology to analyze urban development (e.g., hierarchy, competition, succession). For them, however, the natural environment was reduced to spatial structure. For example, Duncan's *POET model* (population, organization, environment and technology) for describing social processes in no way referred to natural processes or conditions except space (Beus 1993). Some reviewers from the German Human Ecology tradition took a different view (Bruckmeier 2004). Catton and Dunlap (1978), for example, called for Sociology to move beyond Durkheim's dictum that 'a social fact can be explained only by another social fact' (as cited in Beus 1993, p. 94) and to abandon the 'human exceptionalism paradigm' in favor of an ecological paradigm in which the human species is one among other species on earth, sharing their susceptibility to nature. Although frequently cited, this appeal has not yet given rise to substantially new theoretical approaches, although there is a growing body of empirical research from environmental sociologists. A decade later, Beck (1986) started to publish on 'risk society', proposing that modern society in its latest stages should be characterized by its ways of creating and handling environmental risks and redistributing their consequences among its members rather than as a traditional industrial society occupied with emancipation from natural forces and efforts to legitimately handle social inequalities. The neo-Marxist tradition within Sociology tended to become narrowly focused on theories of capital, class and the state. Even the Marxist concept of 'control of the means of material production' was narrowed; private property and ownership signify a purely social or economic relationship, not a coupling between social actors and natural objects. There are, however, contemporary positions where this tradition is retained and explicitly linked to ecological concerns, such as the influential World Systems Theory (cf. Ciccantell and Bunker 1998; Goldfrank et al. 1999; Hornborg and Crumley 2007; Wallerstein 1999). Within Human Geography and Environmental Sociology, efforts have been made to link the economic requirement of capital accumulation to both economic growth and the continuing (over)exploitation of natural resources (Harvey 2014; Schnaiberg and Gould 1994). Another strand is exemplified by Foster (2000), who seeks to reconstruct and build upon Marx's materialist conception of history and his notion of 'metabolism of nature and society'. Jänicke (1988) and, later, Mol and Spaargaren (2000) opened a debate on 'ecological modernization' that claimed that the technological and organizational learning processes of modern societies increasingly led to the amelioration of environmental impacts. All these approaches, however, fall short of an epistemic turn that would allow for relations between the social and the natural that are more symmetrical.

With the German sociologist N. Luhmann, Sociology's influence on Social Ecology reached its peak and turning point. Luhmann's social theory builds on interdisciplinary systems theory, as exemplified in the works of H. v. Foerster, G. Bateson, H. Maturana and F. Varela, and on the formal epistemology of the mathematician G.S. Brown (Luhmann 1984/1995). The resulting general definition of systems as a self-referential operation (termed operationally closed) implies generally conceiving of systems as entities that reproduce their own boundaries toward the environment. Functionally, this means such systems create and use an internal mode of operation, e.g. communication in social systems, that distinguishes the system from its environment.

Combining this interdisciplinary background with a painstaking knowledge of the sociological and philosophical tradition, Luhmann arrives at the logical conclusion that a social system is not composed of humans but of communication between humans. It follows that social systems should be specified by defining how, what and to what effect humans communicate. The focal interest of the Social Sciences, then, would be to study the successes and failures of these communications in the short and long term. This implies distinguishing the operations of social systems from the consciousness of individual persons on the one hand and the socially organized physical condition of these persons as biological organisms on the other.

This theoretical architecture, enriched by a theory of communication and a theory of sociocultural evolution, enabled Luhmann to develop a social theory (Luhmann 1997/2012) that was unprecedented in its reach, complexity and sophistication. Socioecologically, Luhmann's theory thus marks the antipode to Ehrlich's understanding of the social as an aggregated and essentially undifferentiated human population.

Applying social systems theory to socioecological research, however, is an intricate and demanding task. Under the lens of this theory, the seemingly compelling idea of social and natural systems directly interacting with each other needs to be replaced by a concept of a complex network of structurally coupled systems in which physical embedding and societal self-regulation are attributed to three different system types: natural, human and communication (Sieferle 1997, 2011; Weisz 2002; Weisz and Clark 2011; Weisz et al. 2001).

In his book *Ecological Communication*, Luhmann applies his theory to investigate the question of why modern societies are facing so many difficulties in adequately reacting to the disturbances they create in their natural environment, even if these disturbances might turn out to be detrimental in the long run (Luhmann 1986/1989). In essence, Luhmann attributes the inability of modern societies to cope with global environmental change to exactly the same social structures (i.e., functional differentiation) that constituted the decisive evolutionary advantage of modern societies over traditional ones. Social Ecology noted that this was contingent on an unprecedented ability to utilize energy resources, which in turn created environmental change at a planetary scale (Weisz et al. 2001). Any contemporary observer of the international COP negotiations[1] to reach a binding climate mitigation treatment will find ample evidence for Luhmann's analysis from 1986. In conclusion, Luhmann's social theory allows for, but does not directly explore, the relational biophysical conditions of sociocultural evolution.

1.3 Society's Biophysical Structures

1.3.1 Energy and Society

The idea of energetic evolutionism, namely, that the control of energy matters for society and even determines the advancement of civilization, has a long tradition in social theory, prominently represented by Spencer. In his *First Principles* in 1862, the process of societal advance and the differences in stages of advancement among societies can be accounted for by energy: the more energy a society is able to consume, the more advanced it is. Societal progress is based on energy surplus. First, a surplus enables social growth and social differentiation. Second, it provides room for cultural activities beyond basic vital needs. Similarly, the beginnings of Cultural Anthropology were marked by energetic evolutionism (as in the works of Morgan 1877/1963). Along a less ideological vein, Cottrell (1955) offered a careful analysis of the relevance of the sources and amounts of societally available energy for social processes. The physicist V. Smil published periodic compendia, from *Energy in the Biosphere and Civilization* (1991) to *Energy in Nature and Society* (2008), that compiled encyclopedic knowledge on how energy matters socially and economically. Another physicist, R. Ayres, has presented convincing theoretical and empirical evidence that the expenditure of useful work (i.e., exergy) was and is key to economic growth (Ayres and Warr 2005). The historian Sieferle (1982/2001b) analyzed the rise of the United Kingdom (UK) in industrialization and political hegemony as an outcome of its 'subterranean forest', that is, its use of coal, which gave the UK access to many times more energy than if its entire territory had been covered with forest that was harvested and burned as an energy source. Current research is stimulated by the issue of reducing fossil fuel consumption both to address the impending 'peak oil' (and peak fossil fuels not too far away; Murphy 2012) and to avoid dangerous climate change and its potential consequences for economies and societies. What would be the potential consequences of changing society's energy base and of possibly reducing the energy intensity of social processes altogether?

[1]Since the mid-1960s, annual 'Conferences of the Parties' (COP) have been held within the United Nations Framework Convention on Climate Change (UNFCCC). The 'parties' are countries classified by the Convention into various groups with different obligations.

1.3.2 Land Use and Food Production

That societies extend over territories and restructure them for social purposes, with severe consequences for social as well as natural processes, is not a new issue in the Social Sciences; indeed, it has gained substantial momentum. Boserup (1965, 1981), in her continuation and in her critique of Neo-Malthusianism, was at odds with the development policies of her time by arguing for and empirically demonstrating social learning processes in the face of population growth and food scarcity. She was able to show that traditional agriculture found ways to accommodate feeding more people by intensifying land use (and not, as in the Malthusian paradigm, by extending agricultural area). Land-use intensity is an essential aspect of the human use of terrestrial ecosystems. In the course of history, the intensification of land use allowed humans to overcome Malthusian traps and to both support population growth and improve the supply of food and other products dependent on photosynthesis. It helped to achieve increases in agricultural production without requiring proportional increases in the area of agricultural land. However, thanks to intensification, most industrialized countries increased the volume of agricultural output despite shrinking agricultural areas in the last several decades, if not centuries. In the industrial part of the world, we find reforestation instead of the long-term deforestation of the past (although possibly at the expense of deforestation in developing countries). However, increasing land-use intensity has often been associated with detrimental effects on ecosystem functioning, such as soil degradation, groundwater and air pollution and biodiversity loss. Such processes have had negative effects on the ability of ecosystems to sustain vital ecosystem services, thereby potentially jeopardizing human well-being in the end. Under traditional agriculture (which prevailed worldwide until the 1960s), increased food output per unit area was achieved through increased investment of human labor (Boserup 1981; Netting 2010). However, this generated an incentive for high fertility to provide the necessary labor power, and this drove population growth. When fossil fuel use allowed for the industrialization of agriculture (mineral fertilization, pesticides, tractors), this mechanism changed. Agriculture turned from a supplier to a consumer of energy (Pimentel et al. 1973) and started to create toxicological hazards, such as those documented in R. Carson's famous book *Silent Spring* (1962), which examined the risk of poisoning along the whole food chain. Currently, the debate centers more on the risks of genetic engineering (see, for example, the Nature Special Feature 2013). The issue of land use and land cover change has mobilized a large research community, most recently the international program on *Future Earth* (http://www.icsu.org/future-earth), which addresses food security, diets, carbon emissions, biodiversity losses, climate and habitat change in broad interdisciplinary cooperation.

1.3.3 Social Metabolism/Ecological Economics/Industrial Ecology

As early as Marx, social metabolism with nature was at the core of human labor and society (Marx 1867/2010), leading to a philosophical/sociological debate on capitalism introducing a 'metabolic rift' (Foster 2000; Schmidt 1971) between humans and the environment. These considerations were (unknowingly) reintroduced from quite another angle by Ayres and Kneese. They claimed that the common failure of Economics results from viewing the production and consumption processes in a manner that is somewhat at variance with the fundamental law of the conservation of mass (Ayres and Kneese 1969, p. 283). They argue that there must be uncompensated externalities unless one of the following three conditions prevail. Condition one: all inputs of the production process are fully converted into outputs without unwanted residuals along the way. Condition two: all final outputs (commodities) are utterly destroyed or made to disappear in the process of consumption. Condition three: the property rights are so arranged that all relevant environmental attributes are in private ownership, and these rights are exchanged in competitive markets. They state that none of these conditions can be expected to hold; thus, environmental policies addressing wastes and emissions inevitably fall short of succeeding unless the full process of industrial metabolism (Ayres and Simonis 1994) is taken into account. Similarly, Georgescu-Roegen (1971), in arguing that mainstream economic theory and modern economies are at variance with thermodynamics and the law of conservation of mass, established a theoretical foundation for Ecological Economics.

In the 1990s, an operational picture of the full material metabolism of industrial societies emerged, its respective indicators were developed in an internationally comparative way and the World Resources Institute published two consecutive influential reports on the new model (Adriaanse et al. 1997; Matthews et al. 2000). The basic model places material flows within a wider picture of social metabolism (Fig. 1.1) that has become something like a paradigmatic mind model of the field.

By conceptually linking metabolic flows with biophysical stocks in this way, it became possible to define boundaries for social systems (both vis-à-vis their natural environment and vis-à-vis each other) and to create a consistent metric for material and energy flows for social systems on other scales (local communities, firms or cities). For nation states, material flow accounting (MFA) has become a regular part of public statistics in Japan, in the European Union (EU) and in several other countries (Fischer-Kowalski et al. 2011). This allows the provision of reliable annual accounts of material use in physical terms and their comparison across time and with economic accounts.

On the global scale, this is easier to do because it is only necessary to add up the extraction of raw materials that occurs during a year, and one can ignore the complex network of trade that distributes these resources to the world's countries. The International Resource Panel (UNEP 2011) saw strong public approval for publishing the eightfold increase of global resource extraction during the

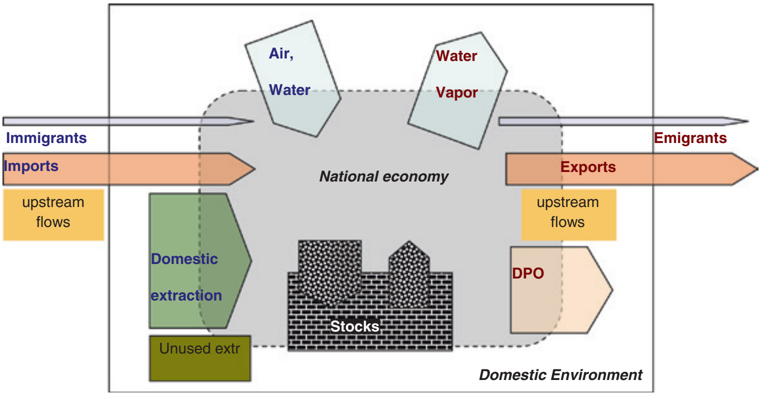

Fig. 1.1 The material metabolism of a national economy. (Source: Fischer-Kowalski et al. (2011), modified from Matthews et al. 2000). DE = Domestic extraction (amount of materials extracted from national territory for direct use). Imports = direct material input from trade (weight at border). Exports = material amounts exported (weight at border). DMI = direct material input = DE + imports. DMC = domestic material consumption = DE + imports–exports. Indirect (or embedded) material flows upstream of imports (and exports) can be expressed as raw material equivalents (RMEs). Total material requirement (TMR) = DE + unused (domestic) extraction + imports + unused extraction in country of origin. Total material consumption (TMC) = TMR—exports—unused extraction of exports. Domestic processed output (DPO) consists of wastes, emissions, dissipatively used materials and deliberate deposition (e.g., fertilizers). Balancing items: air and water contained in materials and that evaporate during production processes or that are drawn into commodities during production (e.g., oxygen in combustion)

20th century, with each of the following fractions increasing: biomass, construction minerals, fossil energy carriers and metals (incl. industrial minerals). Whereas societies at the beginning of the century had reproduced themselves mainly on biomass inputs (i.e., firewood and food for humans and animals), they increasingly turned to so-called nonrenewable resources, such as fossil fuels and ores (Krausmann et al. 2009). During this century, biophysical stocks also increased. The human population, for example, increased fivefold. In addition to the substantial population growth, metabolic rates—that is, resource use per person—increased, doubling from less than five metric tons per person per year to nearly ten metric tons. At the same time, the world gross domestic product (GDP; at constant prices) and average income per person increased 23-fold. Such a 'decoupling' of resource use and income is mainly due to technological progress, which allows the production of more value with less input but also feeds into further growth of resource consumption.

There is a rich body of literature comparing the resource requirements of nation states (e.g., Weisz et al. 2006 for the EU) along with their resource efficiencies (e.g., Schandl and West 2010 for Asia and the Pacific), their trade patterns (e.g., Dittrich and Bringezu 2010) and their growth in biophysical stocks (Müller 2006; Pauliuk et al. 2013). On the other end of the metabolic process, there is particular research interest in greenhouse gas emissions (which can be calculated from fossil fuel use, livestock numbers and steel and cement production) directly occurring within countries or indirectly caused by trading. These emissions are, of course, very relevant for climate policies.

Increasingly, the metabolism of cities also comes into view. City planning is an important means to reduce resource consumption while maintaining the same levels of welfare. Substantial amounts of energy for heat and transportation, construction materials and land can be saved through appropriate spatial structures (Kennedy et al. 2007; Weisz and Steinberger 2010).

Giampietro et al. (2012) choose a somewhat different metabolic approach. They undertake a 'Multi-Scale Integrated Analysis of Societal and Ecological Metabolism' (MuSIASEM) that systematically relates human labor, exosomatic energy use and economic output to describe the metabolic patterns of various types of social systems (from households to farms to national economies, stratified into sectors). This approach is seen as a continuation of Georgescu-Roegen's (1971) foundational work on 'Bioeconomics', influencing the emergence of Ecological Economics.

1.4 Identifying Environmental Impacts of Human Activities

In the 1970s, the so-called *IPAT equation* (Eq. 1.1) was developed from a debate about the relative importance of population growth, on the one hand, and growth in affluence, on the other, in determining human impacts on the environment (Chertow 2001; Ehrlich and Holdren 1971). IPAT is the lettering of the following formula:

$$\mathbf{I} = \mathbf{P} \times \mathbf{A} \times \mathbf{T}, \tag{1.1}$$

where **I** stands for (environmental) impact, **P** for population, **A** for affluence and **T** for technology. This formula has been repeatedly applied to estimate various environmental impacts such as land use, resource use, pollution, CO_2 emissions and the *ecological footprint* (see below). In more statistically elaborate applications (e.g., Dietz et al. 2007), regression analysis is used to determine the relative weight of the components and to calculate nonlinearities and interactions, respectively. Empirical results do not strongly confirm the original hope attached to this equation, namely, that improvements in technology would neutralize at least some of the detrimental effects of population growth and increasing affluence; in some cases, the contrary has even been found. Schandl and West (2012) found the increasing affluence of Asian and Pacific countries to be enhanced by technology changes in their impact on CO_2 emissions. This is highly plausible as economic growth in developing countries typically implies a shift toward using fossil fuels.

Another widely used approach to describing human environmental impact is the so-called ecological footprint (EF). In 1996, Wackernagel and Rees published the

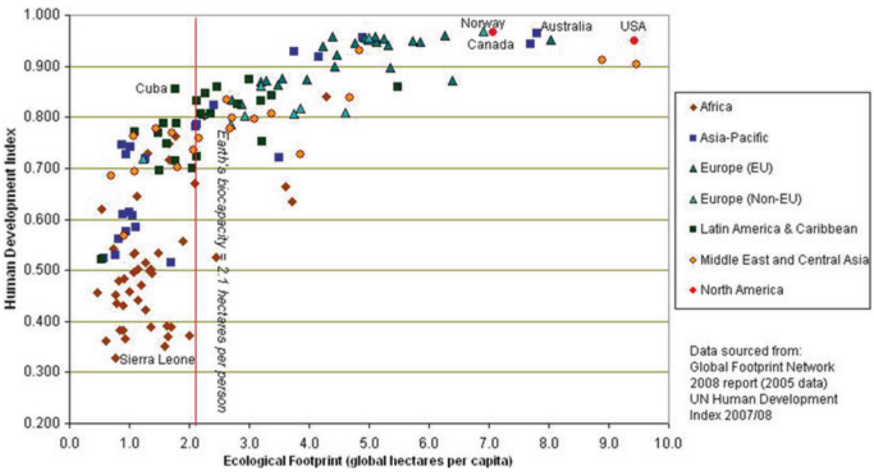

Fig. 1.2 Interrelation between the Human Development Index and the ecological footprint (EF). (Source: received from the Global Footprint Network by data request in August 2013, http://www.footprintnetwork.org)

book *Our Ecological Footprint: Reducing Human Impact on the Earth*. Ecological footprint analysis compares human demands on nature with the biosphere's ability to regenerate resources and provide services. It does this by assessing the biologically productive land and marine area—the 'global hectares'—required to produce the resources a population consumes and to absorb the corresponding waste using prevailing technology. Assessment of the per capita EF is a means of comparing consumption and lifestyles and checking them against nature's ability to provide for this consumption. Despite several modifications, there are still several methodological criticisms of this indicator, such as how different land productivities are taken into account (see Haberl et al. 2004) and how trade can be integrated into the picture (see Grazi et al. 2007). Nevertheless, it is doubtlessly one of the most powerful tools in public communication (Fig. 1.2).

The tool can inform policy by examining to what extent a nation uses more (or less) than is available within its territory or to what extent the nation's lifestyle would be replicable worldwide. The footprint can also be a useful tool to educate people about carrying capacity and overconsumption, with the aim of adjusting personal behavior. EFs may be used to argue that many current lifestyles are not sustainable. Such a global comparison also clearly shows the inequalities of resource use on this planet at the beginning of the 21st century.

From a Social Science perspective, these indicators and analyses of environmental impact fail to account for complexity on the social system side of the process, and they usually lack a coevolutionary perspective. While humans can have detrimental impacts upon nature, the storyline does not include how nature hits back, nor does it allow understanding the adjustments human societies make (or are forced to make).

Something of this type is attempted by the so-called *DPSIR model* (see Fig. 18.4) used by the Organisation for Economic Co-operation and Development (OECD) and the European Environmental Agency (EEA), where D = drivers, P = (environmental) pressures, S = states (of the environment), I = (environmental) impacts and R = (policy) responses. This is postulated to be a causal chain in which, for certain social reasons ('drivers'), pressures are exerted upon the environment that trigger changes there, and in the end, the loop is closed by society reacting to those changes with (presumably ameliorating) policies. Still, insofar as this model focuses on social processes, it does so only very narrowly (Stanners et al. 2007).

1.5 Biohistory and Society-Nature Coevolution

There is a long tradition in the Social and Historical Sciences of distinguishing qualitatively different modes of societal organization, of subsistence, of production and of stages of civilization. The distinctions drawn and the criteria upon which they are drawn vary, but they hardly account for society-environment relations or the environmental consequences of human activity.

It is the special achievement of Sieferle (1997) to regard the modes of societal organization not simply as socially or socioeconomically distinct but to systematize them so that they can be characterized as socioecological patterns, comprising social organization (in the widest sense of the word), concomitant modifications of the environment and intended or unintended environmental impacts. Key to the distinctions Sieferle draws is the source of energy and the dominant conversion technology of the energy a society uses. The charm of this classification is that it helps understand the differences in functional problems societies face when trying to establish and maintain themselves within their environment and the evolutionary advantages and drawbacks that occur, thereby providing some clue to the directionality of change. Sieferle distinguishes the hunting and gathering mode, the agrarian mode (with some subdivisions) and the industrial mode. The energy system of hunter-gatherers is 'passive solar energy utilization'. They live on the products of recent photosynthesis (plants and animals for food, firewood for heat). That they use fire to cook (rather grill) their food widens the spectrum of edibles; nevertheless, only a very small fraction of their environment qualifies as food. Its collection requires mobility, both on an everyday basis and seasonally, and allows only for very low population densities. In contrast, the agrarian mode—an offspring of the Neolithic revolution that occurred (although at different times) on all continents but Australia—is based on 'active solar energy utilization'. This means that certain areas are cleared of their natural vegetation and that solar energy in these areas is, as far as possible, monopolized for edible plants (Netting 2010). In effect, this leads to extensive deforestation of the Earth (and the enrichment of the atmosphere with the CO_2 that previously had been stored in trees and soils), to a sedentary way of life and to a large human labor burden (that even increases with progress in technologies to raise returns on land; Boserup 1965, 1981). The sedentary way of life (plus milk from livestock and ceramics to boil liquids) allows for much greater fertility, and the large labor burden motivates people to have children to share the labor. Thus, high population growth creates high population densities and an expansion of the agrarian mode across the world. Control of territory, tools, livestock and stored reserves is essential, and frequent territorial conflicts produce specialized classes of people to defend and attack territories, social hierarchies to control them and urban centers. In many parts of the world, these systems develop into major empires and civilizations that ever again collapse (Diamond 2005; Tainter 1988).

In the 17th century, a new energy regime emerged: a fossil fuel-based energy system that supplied society with an amount of energy never before accessible. In the UK, the use of coal instead of the increasingly scarce fuel wood allowed a process of urban growth and manufacture. Meanwhile, textile production for export became very profitable, and sheep gradually crowded out farmers growing food. The invention of the steam engine finally kicked off what is known as industrialization. This turn of history in Europe ('The European Special Course', Sieferle 1997, 2001a), as some argue, could also have happened in the East (Pomeranz 2000) or, perhaps, not at all. It caused large-scale ecological and social transformations and continues to spread from the industrial core countries (currently comprising approximately 20 % of the world's population) to the (much larger) rest of the world at an accelerating speed (Fischer-Kowalski and Haberl 2007). It remains an open question whether the ultimate exhaustion of fossil fuels, a detrimental transformation of the Earth's climate system, or politically guided change will bring this energy regime to a close; it will have sustained itself for a much shorter period than the previous regimes.

There is also an interesting new research area emerging from ecological research that addresses long-term processes and observes a global network of local and regional habitats across time, the sites of so-called Long-Term Ecological Research (LTER). Recently, this research has extended to the social processes and has become an LTSER network (Long-Term Socioecological Research, see Singh et al. 2013). A new term that emerged in this context is 'socio-natural sites' (SNSs), denoting places where a long history of human interventions in the environment has generated ever-changing structures in a coevolution of social and natural processes (Winiwarter et al. 2013).

1.6 Regulation, Governance and Sustainability Transitions

The good governance—or lack thereof—of the commons is a long-standing socioecological theme. Taking a point of departure from Hardin's (1968) *Tragedy of the Commons*, Elinor Ostrom's book *Governing the Commons* (1996) stimulated a rich strand of research (and won her a Nobel Prize in Economics). Her work was foundational for the new Institutional Economics. The focus of her research was on how humans interact with ecosystems to maintain long-term sustainable resource yields. She conducted field studies, for example, on the management of pastures and irrigation networks by locals and documented how societies have developed diverse institutional arrangements for managing natural resources and avoiding ecosystem collapse in many cases, even though some arrangements have failed to prevent resource exhaustion. Ostrom (1996) identified several 'design principles' of stable, local common pool resource management, such as the following:

- Clearly defined boundaries (effective exclusion of external un-entitled parties);
- Collective-choice arrangements that allow most resource appropriators to participate in the decision-making process;
- Effective monitoring by monitors who are part of or are accountable to the appropriators;
- A scale of graduated sanctions for resource appropriators who violate community rules and mechanisms of conflict resolution that are cheap and easily accessible.

In her later work, these principles were expanded to include several additional variables believed to affect the success of self-organized governance systems, including effective communication as well as internal trust and reciprocity.

Ostrom and her many co-researchers have developed a comprehensive 'Social-Ecological Systems (SES) framework', within which much of the still-evolving theory of common-pool resources and collective self-governance is now located (Ostrom 2009). A strong research community that utilizes these approaches is the so-called Resilience Alliance, a network of institutions and people sharing a paradigm of socioecological systems, which they define as 'a multi-scale pattern of resource use around which humans have organized themselves in a particular social structure (distribution of people, resource management, consumption patterns and associated norms and rules).' The aim of resilience management and governance is to keep the system within a particular configuration of states (system 'regime') that will continue to deliver the desired ecosystem goods and services. The system should not move into an undesirable regime from which it is either difficult or impossible to recover (see also Gunderson and Holling 2002). The Resilience Alliance network[2] publishes the influential open access journal *Ecology and Society*. A somewhat related approach has been advanced by R. Scholz and colleagues, who address 'human-environment systems' (Scholz 2011).

The core concept employed in the Frankfurt approach to Social Ecology is that of 'societal nature relations' (*gesellschaftliche Naturverhältnisse*). The focus of the Frankfurt approach is on the *relations* between society and nature in terms of the various societal *regulations* that define these relations. Operationally, this approach focuses on what they consider *basic* societal nature relations, which,

[2]http://www.resilience.org/index.php/key_concepts.

being related to basic human needs, are indispensable for individual and societal reproduction and development. The link to the concept of human needs turns societal nature relations into an irreducibly *normative* concept: the basic societal nature relations should be *regulated* in such a way that *all* humans are able to meet their basic needs (Becker et al. 2011, p. 79). The Frankfurt approach defines as its 'epistemic object' the 'crisis of societal nature relations' (Becker and Jahn 2006, p. 19). This definition is normative in that it presupposes the existence of a crisis, that is, a radical deviation of the 'is' state from an 'ought' state of societal nature relations. The purpose of Social Ecology is thus to generate the knowledge necessary to understand this crisis and to react to it in the sense of helping establish the 'ought' state of societal nature relations. The core research question of Social Ecology is thus, 'How can the crisis-ridden societal nature relations be perceived, understood and actively shaped?' (ibid., p. 12). In the 1990s, the German government established an interdisciplinary research program on 'social-ecological research' that enforced an orientation toward basic needs and demanded the strong involvement of stakeholders, thus strengthening the policy relevance of socioecological research in Germany over many years.

A somewhat related approach to managing coupled human-environment systems draws upon the Dutch societal transitions management school. In contrast to the resilience alliance tradition, the Dutch school focuses on technical and social systems rather than ecological systems. The core concern is the existence of 'persistent' and 'wicked' problems in social system functioning that can only be overcome by a systemic transition. Hence, a socioecological transition (SET) is a transition between two dynamic equilibria, that is, a shift from one more or less stable state to another. The typical model of a transition is the S-curve, which allows for the distinction of discrete phases of transition. There is a 'pre-development phase', in which some processes start to deviate from the dominant pattern; next is the 'take-off phase', where a departure from the original equilibrium can be observed; then there is an 'acceleration phase', where change accelerates in a non-incremental, disruptive and potentially chaotic manner; and finally, there is a 'stabilization phase', where the rate of change declines and a new dynamic equilibrium is reached (Rotmans et al. 2001). The nature of transitional dynamics is described in terms of a generic pattern that consists of a sequence of mechanisms that result in irreversible changes in the system. A key pattern is denoted by 'niches'—individual technologies, practices and actors outside or peripheral to the regime—as the loci for radical innovation (Geels 2005). Niches emerge and cluster, and by empowering a niche cluster, a niche regime unfolds. This niche regime becomes more powerful as the incumbent regime weakens. Finally, the niche regime becomes dominant and takes over the incumbent regime. The underlying mechanisms are variation and selection, adaptation, emergence, clustering, empowerment, transformation, decay and development. Transition management draws together a selective number of frontrunners in a protected environment: an arena. To effectively create a new regime, agents are needed at a certain distance from the incumbent regime. However, the continuous link with the regime is important. Therefore, regime agents are also needed, particularly change-inclined regime agents. Because of its methodological concept of transition management, this approach is frequently denoted the 'Multi-Level-Perspective' (MLP) and is linked to the term 'adaptive management'. It was addressed by both the Global Energy Assessment (GEA 2012) and the United Nations Environment Programme (UNEP) to frame their new modeling approach (UNEP 2013).

Fischer-Kowalski and Rotmans published a comparative analysis of the Vienna and Dutch approaches to socioecological transitions (SETs). The Vienna approach to Social Ecology employs a clearly defined notion of SETs, which are conceived as shifts between 'sociometabolic regimes'. They define a sociometabolic regime 'as a dynamic equilibrium of a system of society-nature interaction' (Fischer-Kowalski and Rotmans 2009). Binder et al. (2013) recently published a systematic comparison of frameworks for analyzing social-ecological systems (SES), identifying ten different frameworks. The broadness of this spectrum shows how strongly current research communities feel a need to systematically address society-nature interrelations.

Many of the Social Ecology approaches reviewed here are highly visible among the Natural Sciences as well, particularly those segments that address issues of sustainability. Although they may be less well received among social scientists who follow their traditional disciplinary pathways, an open mind toward paradigmatic change could involve the Social Sciences more intensively in an interdisciplinary discourse about humanity's long-term future on Earth.

1.7 The Distinguishing Characteristics of the Vienna Social Ecology School

The beginnings of the Vienna Social Ecology School date back to the year 1986, when the then 'Interuniversity Research Institute for Distance Education' (IFF) employed Marina Fischer-Kowalski to start a program on society and environment. She arrived with a funded research project on 'Social causation of burdens on the environment'. The name Social Ecology, later chosen in distinction to Human Ecology, was born out of the team's conviction that it was not the human species that mattered but rather the social (and economic and technical) organization this species was evolving. The name may have been a bit misleading as there existed an older US American tradition of the same name. This movement—exemplified in the Institute for Social Ecology in Vermont—emerged from the idea of deep ecology (see Bookchin 1984) and continues to be centered on eco-activism and a new environmental ethic (see Lejano and Stokols 2013). The Viennese understanding of Social Ecology was fundamentally different. It insisted on interdisciplinarity across the 'great divide', a term coined by Snow (1956) to denote the rift between science and the Humanities, and it is basically functionalistic. This Social Ecology has much more in common with its sister fields of Human Ecology, Ecological Economics, Industrial Ecology, Ecological Anthropology, Environmental Sociology and Environmental History, all of which address sustainability issues in a more or less interdisciplinary way.

The above-mentioned fields of research still bear the traces of their disciplinary roots and thus have similar but distinct views on sustainability. Traditional Human Ecology builds largely on ecological concepts (Young 1974) but entertains a rather simple understanding of society and the economy. Ecological Anthropology takes most of its empirical insights from studying non-Western cultures, and it receives much theoretical inspiration from biology (see Lutz 2001). Ecological Economics focuses on transforming or even replacing the body of theory known as Neoclassical Economics with a new understanding that seeks to integrate the physical aspects of the economic process into the center of economic theory (Ayres and van den Bergh 2005; Boulding 1966; Daly 1977; Georgescu-Roegen 1971; Gowdy and Erickson 2005; Martinez-Alier 1987). Industrial Ecology, partly born out of the realization that Ecological Economics has engaged too much in academic disputes, pays less attention to Macroeconomics and is mostly interested in technology transitions, material flows and practical applications (Ayres and Ayres 2002; Bourg and Erkman 2003) along with a strong, yet so far theoretically insufficiently developed, aspiration to incorporate the 'human dimension'. Finally, within Environmental History and Environmental Sociology, it is still a matter of debate whether the idea of addressing the relations between nature and history or nature and society in a biophysical sense should be a legitimate core question (Benton 1991; Winiwarter and Knoll 2007), although progress is being made within Sociology (Dunlap 2015).

It is easy to detect what these fields have in common: they address interactions between a 'social' and a 'natural' domain, a topic increasingly considered to be the core of 'sustainability sciences' (Kates et al. 2001). For sustainability science, understanding and transforming society-nature relations is simply 'the sustainability challenge'. In the same vein, the distinguishing element is also obvious: it is precisely how the 'social' is specified.

The ambition of Viennese Social Ecology is to conceptualize society

- comprehensively: not solely as economy, technology, culture, or Western industrialized societies;[3]
- as sufficiently complex: as an autopoietic system, not as an aggregate of humans or groups of rational actors;[4]
- as historically variable: implying that from a long-term and world historical perspective, different modes of subsistence (or sociometabolic regimes) are distinguished.[5]

[3]This might be considered a heritage from Ecological Anthropology.

[4]Maintaining the heritage from Maturana and Varela (1975) and Luhmann (1984/1995).

[5]This reflects the heritage from classical political economy and universal history.

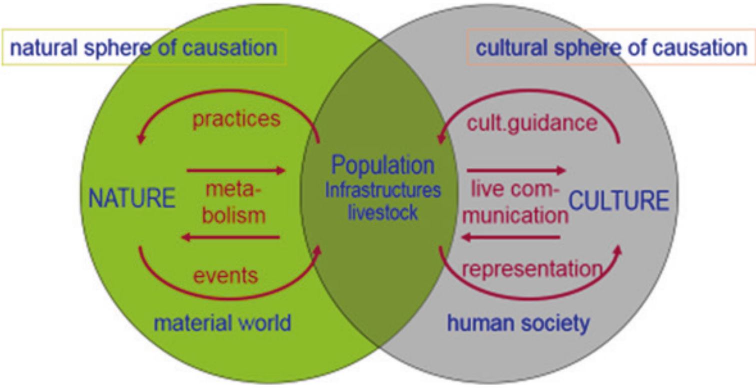

Fig. 1.3 The conceptual model of society-nature interaction developed by the Vienna Social Ecology School. (Elaborated after Fischer-Kowalski and Haberl 2007, p. 13; Fischer-Kowalski and Weisz 1999)

At the same time, it seeks to incorporate a sufficiently complex and realistic understanding of the material world, which means taking Natural Science concepts seriously and incorporating them at a conceptual and empirical level.

The metatheoretical position of Viennese Social Ecology is an epistemology based on distinctions that are not justified by arguing that something is ontologically given but are rather selected for their usefulness to inform insights, pose new research questions and foster interdisciplinary cooperation. In this context, the distinction between culture and nature is particularly relevant. What would be the justification for Social Ecology to start with the distinction between a natural and a cultural realm? This justification lies in the possible means of intervention. Intervention within society must refer to cultural meaning. Although physical interventions can be very effective—though sometimes not very targeted—in creating new communication, society can ultimately only be reached through communication (Luhmann 1984/1995).[6] This is a decisive observation as unsustainable development is a problem of society and not a problem of nature. Conversely, interventions in nature, or into the physical world, can only be effective by means of physical forces—nature is not susceptible to cultural or symbolic action. In effect, society must be conceived not as a communication system only but as having access to and being able to control physical forces, that is, to develop means of 'colonizing' nature via physical interventions (see Fig. 1.3).

One of the early insights of the Vienna team was that a sufficiently complex concept of society as a whole would be essential for a theoretically ambitious and

[6]Imagine 9/11 and no one talking about it!

practically effective Social Ecology, whereas the attempt to conceptualize 'nature' as a whole was not very promising. The complexity of the natural world can better be considered by drawing upon various meso-level concepts from different Natural Sciences than by aiming at an overall understanding of nature.[7]

The *conceptual model* shown in Fig. 1.3 contains some characteristic elements that are distinct from similar conceptual models. It is a heuristic that highlights the intersection of the Cartesian distinction between the material and symbolic (cultural) realms as mutually exclusive domains, on the one hand, and of the material world and human society, on the other hand, as comprising all of culture and specific elements of the material world. Therefore, the natural and cultural spheres of causation partly overlap in society; human society is thus a hybrid of the two realms (Boyden 1992; Fischer-Kowalski and Weisz 1999).[8]

Social metabolism is the key link between society and the natural environment. To reproduce its biophysical structures, society requires a continuous flow of energy and materials that need to be extracted from and eventually released to the environment (Ayres and Kneese 1969). In the same vein, communication is the key link between individual human consciousness (subsumed under *population* in Fig. 1.3) and *culture* (Luhmann 1984/1995).

Following the bended arrows in a recursive way, the conceptual model describes the society-nature coevolution as a self-referential dynamic with the selective forces being contingent on the internal selection pressures of the systems coevolving. Society intervenes in nature (through labor, technology and capital, summarized as *practices* in Fig. 1.3) to modify it according to its needs (e.g., agriculture, construction activities). Society's biophysical structures are susceptible to physical forces from nature, and through communication, these forces are represented culturally, interpreted as rewards for society's efforts (e.g., a large harvest), as catastrophes (e.g., a flood), or as potentially irrelevant. In the other direction, culture supplies guidance/programs for collective decisions and actions; certain culturally guided regulations lead to physical alterations in natural processes that, in turn, may or may not lead to new forces, intended or unintended, exerted from nature upon society. These changed forces might become culturally represented in one way or another (or even pass unregistered) and may or may not modify cultural guidance/programs for future action upon nature.

Conceptually, this heuristic allows us to draw upon Luhmann's fundamental distinction among communicative (termed *culture* in Fig. 1.3), conscious and physical modes of operation. Consequently, we can draw upon all important insights that are contingent on this theoretical architecture. At the same time, this heuristic conceptually allows for a direct embedding of society into the physical

[7]Natural scientists would not even consider engaging in something like finding an overall concept of nature—this has always been the realm of philosophy.

[8]Recent similar conceptualizations may be found in Liu et al. (2007), who discuss the complexity of coupled human and natural systems, and in Becker (2013), who emphasizes the importance of hybrid structures.

environment by including the human population, the livestock population and all physical artifacts (including infrastructures, buildings, technical equipment and all other kinds of products, usually summarized as *biophysical structures*) into the definition of society.

This conceptualization has benefits and costs. The most important benefit is that a consistent quantitative empirical program can be built upon it. The highly visible contributions to quantify the social metabolism, in terms of material, energy and land use, produced by the Vienna Social Ecology School have amply demonstrated this point (Fischer-Kowalski and Haberl 2007). These insights refer to very different historical circumstances, both contemporary and historical. Contemporary (or industrial, or modern) society-nature relations may be and have been analyzed, but equally well-founded insights into the social metabolism of hunter-gatherers or agrarian societies have been gained, together guiding the comparison across history. Even more so, an explicit theory about modes of society-nature coevolution and the stages in this process could be developed (see Chap. 3 in this volume). Such a quantitative approach strongly facilitates communication with natural scientists and appeals to them—yet another benefit.

One obvious cost is that a focus on quantifying societal material, energy and land use typically alienates social scientists and historians. This could, in principle, be balanced by a more direct exploration of the cross-cutting potential in the underlying heuristic. The overarching term ‘communication’, for example, comprises economic and monetary processes as well as legal processes or decision-making as different media of communication used by different subsystems. The core message of this conceptual model is, therefore, the insight that communication and physical forces operate in different systems and that humans and social systems, as receptive both to communication and to physical forces, are systems in their own right, located at the interface between the symbolic and the material worlds. Nonetheless, the cultural realm is still underexplored in the scholarly work that was guided by this model. One reason might be that a systems theory perspective, if taken seriously, demands a precision in specifying the reference system that does not allow easy conceptual access to other Social Science theories, especially those centered on social actors or values and attitudes. Overall, as will be documented throughout this book, the Viennese School of Social Ecology stands for empirical analysis in a liberal interpretation of methodological pluralism.

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