Conceptualising Long-term Socio-ecological Research (LTSER):
Integrating socio-economic dimensions into long-term ecological research

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Abstract

In order to support the emerging network of long-term ecological research (LTER) sites across Europe, the European Union has launched ALTER-Net, a network aiming at lasting integration of long-term socio-economic, ecological and biodiversity research. Due to its high population density and long history of human habitation, however, Europe's ecosystems are generally intensively used. Social and natural drivers are so inextricably intertwined that the notion of "socio-ecological" systems is appropriate. Traditional natural science-based approaches are insufficient to understand these integrated systems, as they cannot adequately capture their relevant socio-economic dimensions. This is particularly relevant because the EU launched ALTER-Net has an explicit aim to support sustainability, a goal that requires integration of socio-economic and ecological dimensions. As such, LTER is challenged to significantly expand its focus from ecological to socio-ecological systems, thus transforming itself from LTER to long-term socio-ecological research or LTSER. In order to support this transformation, this paper explores several approaches for conceptualizing socio-economic dimensions of LTSER. It discusses how the socio-economic metabolism approach can be combined with theories of complex adaptive systems to generate heuristic models of society-nature interaction which can then be used to integrate concepts from the social sciences. In particular, the paper discusses possible contributions from the fields of ecological anthropology and ecological economics and shows how participatory approaches can be integrated with innovative agent-based modelling concepts to arrive at an integrated representation of socio-ecological systems that can help to support local communities to move towards sustainability.

Key words: agent-based modelling; complex adaptive systems; participation; long-term ecological research (LTER); long-term socio-ecological research (LTSER); society-nature interaction, socio-economic metabolism;

1. Introduction

Long Term Ecological Research (LTER) has gained much significance in the last decades due to the recognition that several relevant questions can only be answered by monitoring and analyzing changes in patterns and processes in ecosystems over long time scales (Hobbie et al., 2003, NRC, 2004) rather than through short-term studies (Dearing et al., 2006). Collecting evidence of the impacts of climate change on ecosystems, for instance, requires a long-term approach, not only because many of the variables are changing slowly, but also because spatial and temporal variability of some of these variables (e.g. seasonal temperatures) make it difficult to discriminate the signal of climate change from the background noise (Greenland and Kittel, 2002). Moreover, ecosystems involve numerous and complex interactions between physical, chemical and biological components, and this complexity may generate dynamics endogenously, thus sometimes masking the effects of changes in exogenous drivers. A large number of parameters and factors must be monitored – that is, measured consistently over long periods of time – in order to be able to reliably detect changes in the functioning of ecosystems and their components. Therefore, most classic LTER sites are small, often comprising only a few hectares. Many LTER sites, above all in the US LTER network, are deliberately selected to represent ecosystems with little current direct human influence in order to facilitate the detection of signals of global environmental change (Haberl et al., 2006).

There is increasing evidence, however, that classical disciplinary ecosystem research is not sufficient to guide action to conserve valuable ecosystems (Delbaere, 2005, Vadineanu, 1998, Vadineanu, 2001). In Romania, for example, six decades of ecosystem research from 1900 to 1960 in the Lower Danube Wetlands System did not succeed in protecting the region from adverse management and development policies. Despite the fact that two LTER sites are located in this region, neo-classical economists, together with those from the field of agriculture, civil engineering and water management, went as far as to regard the wetlands as wastelands. In their opinion, the only “economically viable option” was to utilize the region in a mono-functional fashion (either crop, wood, or fish) by establishing management systems subsidized by high amounts of external energy and material inputs (Vadineanu et al., 2001). Progress could only be made when, from 1970s onwards, ecosystem research was complemented with an understanding of the major anthropogenic drivers. An economic valuation of the gains from multi-functional farming and other ecosystem services helped to convince relevant policy makers to adopt new, bio-economically oriented management strategies for the Lower Danube Wetlands that aim to integrate economic and ecological goals (Vadineanu et al., 2003).

The example of the Lower Danube Wetland System shows that interdisciplinary approaches, in this case a combination of economic and ecological expertise, are required in exploring viable management strategies oriented towards sustainability and nature conservation. The lesson for LTER is that, in order to generate knowledge which would be useful to resolve society’s problems related to sustainability, it needs to extend its focus beyond classical ecological research. Traditional ecological approaches often seem to regard human activities as disturbances to otherwise properly functioning ecosystems (Haberl et al., 2006). If LTER is to contribute in finding solutions to sustainability problems it must go beyond a focus on patterns and processes in ecosystems and their alteration due to changes in global environmental conditions. It has to include an analysis of socio-economic activities that actively change and use ecosystems, and of the socio-economic significance of these ecological changes. In order to be able to do so, LTER would have to include approaches from the social sciences within its framework (Redman, 1999, Redman et al., 2004). This would require a considerable shift in thinking within the LTER community that is far-reaching enough to warrant a re-labelling of the enterprise to "Long Term Socio-Ecological Research," abbreviated LTSER (Haberl et al., 2006).

Such an LTSER approach is consistent with the emerging agenda of sustainability science (Clark et al., 2004, Kates et al., 2001, Parris and Kates, 2003) that emphasizes the sustainable use of natural resources to meet the needs of the present as well as those of future generations. Most ecological problems are due to the ways society interacts with nature. Investigations into the interactions between natural ecosystems and human activities would not only require approaches from the social sciences to be taken into account, but also an up-scaling of present LTER sites to regions in which substantial human populations reside (Wilbanks and Kates, 1999). Obviously, in doing so, scientists are confronted with a complex interplay of various ecosystems and societal dynamics; that is, the focus would change from ecosystems to socio-ecological systems. Although this entails a considerable increase in complexity of the endeavour, it has important benefits. Such integrated LTSER platforms (Haberl et al., 2006) can be of much higher utility than LTER sites in supporting local populations in finding solutions to pressing sustainability problems, thus providing them decision support for viable future options. Furthermore, an understanding of society-nature interaction at local scales would provide reasonable estimates of the level of impact that local activities have on ecosystems compared to impacts caused by processes on larger scales, such as global environmental change.

Such considerations, together with the recognition that European ecosystems are typically used and transformed by humans to a much larger extent than in the USA (due to Europe's much higher population density and long history of human habitation), have motivated a strong orientation towards including socio-economic components in the emerging European long-term ecological research networks. In particular, within its 6th Framework Programme (FP6), the EU commission has set up a Network of Excellence to foster integration of socio-economic and ecological expertise in long-term ecological research. This network, called ALTER-Net (Delbaere, 2005, http://www.alter-net.info), acknowledges the need to integrate socio-economic knowledge in several of its work-packages, but a proper understanding of how to tackle this task, both conceptually and methodologically, is still to emerge. In this paper we will discuss concepts for including social sciences into LTER, thus transforming it to LTSER. By social sciences, we mean only those concepts that could readily be integrated and be beneficial to LTER research and conservation goals, as opposed to a full-scale social science program. The article is organized as follows: First we discuss general concepts of socio-ecological systems. Then we elaborate on some of the general areas where social science could contribute in this regard together with a description of a few social science methods that could prove useful. We conclude by discussing an example from the emerging Austrian LTSER platform in which some of these approaches are currently being tested.

2. Conceptualising socio-ecological systems

2.1 Sustainability science

Sustainability is increasingly seen as a problem of society-nature interaction. A "new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society" (Kates et al., 2001, p. 641). This concept is challenging, as it requires interdisciplinary cooperation across the social/natural sciences divide, and of course LTSER has to be interdisciplinary as well, if it should contribute to monitoring progress towards sustainability. To be successful in this context, it is necessary to observe societies, natural systems, and their interaction over time, asking the following questions: (1) Which changes do socioeconomic activities cause in natural systems? (2) Which socioeconomic forces drive these changes, and what can we do to change them? (3) How do changes in natural systems impact on society? (4) How, if at all, can society cope with the changes it has set in motion? (Haberl et al., 2004).

Natural systems undergo significant changes as a matter of course. For example, temperature, precipitation, sea level, atmospheric chemistry and biodiversity have fluctuated drastically in the last thousands and millions of years, driven by both endogenous (e.g., geological or biotic processes) and exogenous (e.g., meteorite impacts) phenomena (Schellnhuber, 1999, Schlesinger, 1997). Such natural systems may be seen as self-organizing dynamic systems which may be near equilibrium for limited periods, but may as well rapidly flip between different equilibria (Holling, 1986, Scheffer et al., 2001). Thus any discussion of sustainability needs to recognise this intrinsic potential for change and that maintenance of any equilibrium over long time spans is unrealistic.

If equilibrium is unattainable, what else could sustainability mean? Sustainability has been defined as meeting the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987). A more equitable distribution of resources between regions and within nations is also often regarded as one of its cornerstones (UNEP, 2002). Sustainability defined this way is therefore anthropocentric, as it demands that human-induced changes in ecosystems must not affect society's survival or well-being, thus "creating and maintaining our options for prosperous social and economic development" (Folke et al., 2002, p. 3). Some authors stress the need to "expect the unexpected" (Holling, 1986) and improve society's ability to cope with uncertainty and surprise, defined as a situation in which perceived reality departs qualitatively from expectation (Berkes and Folke, 1998, p. 6). This has led to thinking about sustainability as “the capacity to create, test, and maintain adaptive capability” (Holling, 2001, p. 390) which is related to the resilience of social-ecological systems (Carpenter et al., 2001).

An influential definition of sustainability is that societies should live “within the regenerative capacity of the biosphere” (Wackernagel et al., 2002, p. 9266). This focus on the biophysical foundations of sustainability makes it obvious that a transition towards sustainability would not just require minor changes in current trends, but a radical reorientation. Even today, when only about one fourth or maybe one third of humanity lives in relative prosperity, humanity consumes each year an amount of natural resources which would take the biosphere 1.2 years to regenerate (Wackernagel et al., 2002). Hence, analyses of the biophysical dimension of society-nature interaction (Wackernagel, 1999) are of high importance for sustainability science, and also for LTSER.

2.2. Conceptualising Long-Term Socio-Ecological Research

There has been a long-standing debate on whether or not to view the natural world (dominated by biophysical realities such as matter and energy) as distinct from the human world (conceived as a system of recursive human communication and culture) (Croll and Parkin, 1992, Descola and Pálsson, 1996, Teich et al., 1997). This separation of nature and society has its roots in “Cartesian dualism” manifested in the “great divide” between the natural and social sciences. The question on how to view the world – natural and cultural realms as two entities or the latter embedded in the former – remains unresolved and is not within the scope of our paper to discuss. However, the challenge of sustainability requires pragmatic approaches to overcome disciplinary boundaries between the natural and social sciences. One such approach would be to begin by viewing “society as a hybrid of the realm of culture, of meaning, of communication, and of the natural world" (Fischer-Kowalski and Weisz, 1999). In other words, society is seen to be composed of a system of recurrent self-referential communication, and material components, namely, a defined human population as well as a physical infrastructure such as buildings, machines, artefacts in use, and animal livestock, etc.

In order to aid interdisciplinary efforts, therefore, a useful heuristic model of the study of socio-ecological systems can be constructed, as shown in Figure 1, by drawing two overlapping spheres, one depicting the study of "natural" or "biophysical" processes, and a second representing the study of "cultural" or "symbolic" processes, including symbolic communication. LTSER, then would be the integrative field dealing with the processes of coupled socio-ecological systems, thus transcending classical LTER that is focused on more or less undisturbed natural systems, and even "extended LTER" that also deals with strongly human-modified ecosystems.

[Insert Figure 1]

This heuristic model can be used as a mind map to identify and locate the contributions from different disciplines, and to understand the interrelations between them. One research strategy that has been followed is the analysis of material and energy flows between the biophysical structures of society and the other components of the biophysical sphere of causation. This approach, often denoted as "socio-economic metabolism" (e.g., Ayres and Simonis, 1994, Fischer-Kowalski, 1997b, Fischer-Kowalski et al., 1997, Matthews et al., 2000), regards society as a physical input-output system drawing material and energy from its environment, maintaining internal physical processes and dissipating wastes, emissions and low-quality energy to the environment. The central idea of the metabolism approach is to view societies as organising and maintaining flows of materials and energy for their production and reproduction. Such engagements with biophysical processes serve not only to produce and maintain a society's own biological existence, but also that of their livestock and the whole range of artefacts such as buildings, infrastructure, machinery, etc.

The concept of 'socioeconomic metabolism' has already been described elsewhere in detail (e.g., Fischer-Kowalski and Weisz, 1999, Daniels and Moore, 2001). Current work in this context organizes its accounts in a way that is compatible with established tools for societal self-observation, above all, social and economic statistics upon which practically all modeling in economics and the social sciences is based. These tools facilitate the analysis of mutual relations between symbolic (e.g., money flows) and biophysical aspects (e.g., material flows) of society. By means of this "double compatibility" – towards ecological and socioeconomic models and data, – the socioeconomic metabolism approach can establish a link between socioeconomic variables and biophysical patterns and processes.

The analysis of material and energy flows related to economic activities alone, however, is not sufficient to capture society-nature interactions. One important aspect not adequately grasped by the metabolism approach is land use – one of the most important socioeconomic driving forces of Global Change (Meyer and Turner, 1994). Land use can be conceptualised as "colonization of nature" (Fischer-Kowalski and Haberl, 1997, Haberl et al., 2001, Weisz et al., 2001), an approach that emphasizes the fact that these human interventions into ecosystems are undertaken deliberately with the intention to modify natural systems according to society's needs and wants. Colonization intensity in ecosystems can be analyzed empirically by comparing currently prevailing ecosystem patterns and processes with those patterns and processes that would be expected without human intervention. An example of this approach is the calculation of the "human appropriation of net primary production," or HANPP (Vitousek et al., 1986) which is defined as the difference between NPP of potential (i.e. hypothetical, non human-modified) vegetation with the amount of NPP remaining in currently prevailing ecosystems after harvest, i.e. the amount of trophic energy diverted by humans from ecosystems (Haberl, 1997).

The notion of a "MEFA framework - Material and Energy Flow Accounting" has been proposed (Haberl et al., 2004, Krausmann et al., 2004) to describe an integrated, consistent accounting framework consisting of data on socioeconomic metabolism and on the colonization of nature. Three parts of the MEFA framework have been elaborated in considerable detail: (1) Material flow accounting (MFA) has received most attention (e.g., Eurostat, 2001, Weisz et al., 2006). (2) Energy flow accounting (EFA) methods consistent with MFA have been proposed and applied (Haberl, 2001a, Haberl, 2001b). (3) The Human Appropriation of Net Primary Production, or HANPP, proposed almost 20 years ago (Vitousek et al., 1986), has been further developed in a way that makes it consistent with material and energy flow accounting (Haberl et al., 2001). The MEFA framework is useful to analyze how we depend on, and use the following three core functions of ecosystems for humans (Dunlap and Catton, 2002):

1. "Resource supply:" Land serves as a source of inputs for socioeconomic metabolism by providing renewable and non-renewable resources (e.g., air, water, biomass, fossil fuels, minerals).
2. "Waste absorption:" The biosphere absorbs socioeconomic outputs such as wastes or emissions.

3. “Occupied space for human infrastructure:” Humans occupy areas for housing, work space, infrastructure (including transportation), recreation, education, and many other culturally important human activities.

Analyses of socio-economic metabolism and the colonization of nature are important in an LTSER context above all because they can provide a link between natural-science based approaches (due to the obvious relevance of resource extraction, dissipation of wastes, and land use for ecosystems) and approaches from the social sciences. Useful research questions can be derived by asking, for example, what cultural, economic or political conditions are most important in driving changes in socio-economic metabolism and land use, what role individual actors play, etc.

2.3. Dynamics of socio-ecological systems

In a long-term perspective it is particularly important to pay attention to the temporal dynamics of socio-ecological systems. One body of theory that has recently gained attention derives from the recognition that society and nature co-evolve in a non-linear fashion (Abel, 1998, Norgaard, 1994, Weisz, 2002). This notion has led to an interest in the theory of complex adaptive systems as a means to understand socio-ecological systems. In fact, the theory of complex adaptive systems is more a collection of theories rather than a single theory, but these theories share some common characteristics in that they describe socio-ecological systems that are composed of loosely-connected hierarchical structures, whose dynamics are very sensitive to initial conditions, and which exhibit self-organisation, emergent phenomena, and possibly sudden transitions from one stable equilibrium to another (Kay et al., 1999). These characteristics may make such systems unpredictable in some cases. There is a distinction here between ‘complex’ systems and ‘complicated’ systems – both may have large numbers of interacting components, but complex systems behave in a non-linear way in which overall behaviour of the system is difficult to predict from a knowledge of the behaviour of individual components due to positive feedbacks and emergent processes, whereas complicated systems behave in a linear way and are more predictable. Indeed, socio-ecological systems may exhibit behaviours which are both complex and complicated.

The term SOHO, which stands for 'Self-Organising Holarchic Open' systems,' has been proposed to describe ecosystems, based on the concept of a 'holon' (Kay et al., 1999). The term holon was devised by (Koestler, 1967) as part of an attempt to bridge the gap between individual behaviour at the micro-level and aggregate behaviour at the macro-level. A holon is a system that has a unique identity and is semi-autonomous, but in turn is composed of other sub-systems (in themselves holons), and simultaneously forms part of a larger unit of organisation, with the overall system being referred to as a 'holarchy,' or 'hierarchy of holons.' Such holons arise as a result of the system self-organising around an attractor to dissipate the flow of exergy (high quality energy) through itself (Odum and Pinkerton, 1955, Hall, 1995), and, as such, can be seen as non-equilibrium dissipative structures (Prigogine, 1976). As with the adaptive cycle concept, there is an appreciation that in SOHO systems, while their self-organising behaviour provides some ability to maintain themselves at an attractor despite changes in their environment, can also suffer catastrophic collapse or reorganisation into other attractors when certain variables within them reach specific thresholds, or if there is some kind of external perturbation. Which particular attractor domain a system finds itself in, therefore, also depends on its history. A similar concept is that of the Total Human Ecosystem (THE) that includes hierarchy, emergence, autopoiesis, and cross-catalytic networks as properties of such coupled human/environment systems (Naveh, 2000).

Similarly, the Ecosystem Approach, adopted by the Convention on Biological Diversity (CBD) also builds on hierarchy theory (Allen et al., 1993).

Working independently, a number of groups have arrived at similar descriptions of the characteristics of socio-ecological systems, generally recognising that change is an intrinsic property of such systems, and that static equilibrium is seldom reached. For example, from a traditional ecological perspective on succession, Holling has developed the idea of an adaptive cycle (Holling, 1973, Holling, 1986). Initially this was a two-stage model in which the dynamics of biological communities consisted of an r phase or exploitation phase, in which rapid acquisition of resources is a successful strategy, and a k phase or consolidation phase leading to a stable climax-state, in which conservation of accumulated capital is a successful strategy. This model was then extended to include an Ω phase or *creative destruction* phase, in which the k stage breaks down and an α phase or reorganisation phase in which new patterns are emerging (Gunderson and Holling, 2002).

Resilience was postulated to be a function of the potential and connectedness of the system, and to be closely linked to the four phases just described, but to peak and to start declining before the peak of the k phase is reached, due to the increasingly fragile dependence of all the ecosystem components on one another, and increasing vulnerability to both internal and external shocks and stresses. Adaptive cycles were seen to operate at different hierarchical scales at different rates, with transfer of information between scales occurring via a limited number of variables (~5, i.e. ‘the rule of hand’). From time to time, interactions between slower changing variables at one level and faster changing variables at another could trigger entry into the creative destruction and reorganisation phases of one or more of the cycles. These processes can also lead to a new stable system state – as opposed to the traditional view of having one climax state for one system. The combined system of interacting adaptive cycles operating at different scales was termed “panarchy” (Gunderson and Holling, 2002).

This metaphor was extended by conceptualising socio-ecological systems as being located on stability landscapes (in a topological rather than topographical sense) which contain basins of attraction representing a range of possible states with similar characteristics (Walker et al., 2004). Socio-ecological systems were hypothesised to cycle within a particular basin of attraction, although external perturbations at critical times may, depending on circumstances, transform it into a neighbouring basin of attraction representing a significantly different type of system, particularly if it is close to a critical threshold (Walker and Meyers, 2004). Resilience was then defined as the amount of effort required to move from one basin of attraction into another. Basins of attraction and resilience are merely system characteristics, neither intrinsically good or bad, and it is only when particular basins of attraction are considered more desirable than others that the concept of value enters. The notion of sustainability can then be thought of as the process of maintaining the system in a desirable basin. The adaptibility of the system is the degree to which the components of the system can influence its internal dynamics and hence its resilience (Walker et al., 2004).

While these approaches have been proposed by researchers mostly originating from the natural sciences and have then also been applied by interdisciplinary teams, many social scientists prefer the notion of “transitions” between different, qualitatively states in socio-ecological systems, for example, between agrarian and industrial society (Fischer-Kowalski and Haberl, 2006). Transitions are also usually broken down into a formal sequence of phases. A common distinction is between a take off phase in which the status quo is still in place, but there are various symptoms of its initial destabilization, followed by an acceleration phase in which many rapid changes take place, and a subsequent stabilization phase where changes are slowing down and the features of a new equilibrium begin to crystallize (Martens and Rotmans, 2002). A specific feature of the transition idea is that transitions take place between two qualitatively distinct states. No linear, incremental path leads from one state to the other, but rather a dynamic, possibly chaotic process of change. The transition notion allows qualitatively different states to be distinguished, in contrast to theories of growth or modernization that assume a certain homogeneity of the basic setting and gradual change over time. To some extent, socio-ecological transitions as understood in this tradition might be seen as flips between different states in a stability landscape, as suggested by the above-discussed model of Walker et al. (2004), but with the additional condition that these system changes are largely irreversible due to the legacies (Foster et al., 2003) emerging during the transition process.

Spontaneity and emergence are other, important ingredients of the transition notion. It is neither possible for one state to be deliberately transformed into the other, nor for the process to be fully controlled – at least at present. Particularly if, as in sustainability research, the concept is applied to complex systems (such as societies or technology regimes), one is dealing with autocatalytic or autopoietic processes (Varela et al., 1974) to which concepts of orderly governance, steering or management cannot be applied. It is commonly assumed, however, that there is increased potential for disturbance or of intervention into the system during the take-off phase of a transition, when the old interrelations are breaking apart but no clear directionality of change has yet been established (Rotmans et al., 2001, Berkhout et al., 2003). There need not be a contradiction between this three-phase scheme (take off – acceleration – stabilization) and the four-phase adaptive cycle (also called the “lazy eight”) scheme discussed above. However, there is an obvious similarity between the stabilization phase and the highly connected, stable *k* phase and between the pioneer-dominated transient *r* phase and the acceleration phase. Whether or not it is helpful for the analysis of socio-ecological systems to break up the take-off phase in two phases, one of release (Ω) and one of reorganization (α), may depend on the circumstances.

A socio-ecological transition that is currently being investigated in great detail due to its significance for current sustainability problems is the "great transformation" (Polanyi, 1957) from agrarian to industrial society. Historical examples that have recently been investigated include the UK, the forerunner of industrialization, and Austria (Krausmann and Haberl, 2002, Krausmann, 2004, Schandl and Schulz, 2002). These case studies suggest that industrialization replaces one set of sustainability problems – above all those related to balancing land, labour, agricultural productivity and population (Boserup, 1965, Boserup, 1981, Netting, 1993) – with new ones, above all those related directly or indirectly to the surging use of non-renewable resources, most prominently fossil fuels (Haberl et al., 2004, Hall et al., 1986). From the perspective of a member of industrial society – which most researchers are – this could be misinterpreted as a more or less completed process, encapsulated in the safe territory of the past. This point of view neglects, however, that about two thirds, if not three quarters of the world population are currently in the midst of exactly this transition process, thus aggravating many of the global sustainability problems such as atmospheric change, climate change, and rapid land-use change (Fischer-Kowalski and Haberl, 2006).

A theme common to all of these approaches is that, because many aspects of the behaviour of socio-ecological systems are to some extent unpredictable due to cross-scale interactions, emergent properties, and the existence of thresholds, the only realistic way to intervene into them is to follow a process of ‘adaptive learning.’ As societies and ecosystems co-evolve, decisions and actions made within society alter ecosystems and vice versa, and the perception of this co-evolutionary process in turn influences future decisions. This has implications for the role of researchers in the study of such systems – no longer are they external observers, but they have become intrinsic parts of the system, an approach sometimes referred to as ‘post-normal’ science (Funtowicz and Ravetz, 1993, Luks, 1996, Waltner-Toews et al., 2003, Waltner-Toews and Kay, 2005). The task of researchers is to understand the current structure and dynamic processes of socio-ecological systems, to identify possible attractors and the pathways between them, and to inform other stakeholders within the system of possible trajectories. This results in a self-reflective research process, one that explicitly considers the perspectives of involved citizens, scientists, and managers, and the dominant narratives of each of these groups. Cybernetics has termed such a process a second order observation approach. In this kind of research process, the problem of communication between different actors cannot be managed easily (Waltner-Toews and Kay, 2005), but is discussed in more detail in Section 3.4 on participatory approaches below.

2.4. Structure of socio-ecological systems

As already mentioned, socio-ecological systems can be seen as ‘open systems’ operating far from equilibrium (Kay *et al.*, 1999), with material, energy and information flowing both into and out of them. It is the way in which their internal social, economic, and biophysical components are organised in relation to one another that determines how these flows are used and traded (Matthews & Selman, 2006). Networks of different types within socio-ecological systems contribute significantly to their functioning, and hence to their resilience and adaptivity. For example, ecological networks determine the relationships between different species contained in the system (e.g., who eats whom or who lives on whom). Similarly, social networks play an important role in the way that information persists in the system, the rate at which it spreads through the system, and the degree to which this information can be used. Some authors have developed models of social networks to extend the classical approach to innovation diffusion by distinguishing between the effects of initial information passed to a subset of farmers from institutions, and subsequent discussion among farmers themselves (Deffuant et al., 2002).

The structures of such networks have a major influence on the way they function, and there has been significant interest in the theoretical aspects of network structure recently, particularly 'small-world' (Watts and Strogatz, 1998) and 'scale-free' (Barabasi et al., 2000b) networks, and how this structure influences network resilience (Barabasi et al., 2000a). There is a rich literature on modelling studies of the relationship between species diversity and stability in ecological food-webs (McCann, 2000) although there is no clear consensus – in some cases there has been a positive correlation, and in others a negative. For example, a case study found that resilience in ecological food webs (i.e. networks) increased with their connectivity, but was independent of species richness and omnivory (Dunne et al., 2002). These studies were on well-defined but static food-webs (i.e. the networks were not growing), and it may be that part of the reason for these conflicting results is due to the dynamic nature of the relationships. Interestingly, the adaptive cycle discussed above hypothesises that resilience is positively correlated with capacity and connectedness in the *r* phase, but negatively correlated in the *K* phase. Certainly, the socio-ecological systems described by the adaptive cycle framework are dynamic and growing rather than static, so there is a clear need to investigate the relationships between these properties in that context. Barabási et al. (2000b) It was found that scale-free networks could be generated, firstly, if they were growing, and secondly, if new additions to the network were not attached randomly, but ‘preferred’ already highly connected ones (Barabasi et al., 2000a). It seems reasonable to assume that other network architectures can be generated by different assembly rules.

In relation to socio-economic networks, the role and development of inequality of the nodes is of particular interest. Tilly’s concept of ‘durable inequality’ that explains the process by which networks are formed and grow, and the concomitant diffusion of new ideas resulting in rewards persistently accumulating to particular groups (e.g. wealthier households, and men) is an area that needs to be explored (Tilly, 1988). Three different types of information processing in a socio-ecological system have been proposed which they have termed egalitarian, hierarchical, and distributed, and which can be related to the structure of the social networks operating (van der Leeuw and Aschan-Leygonie, 2005). However, while much of the evolution of inequality, networks, and information transfer has been theorised, little has been simulated, despite it being identified as an emerging research agenda. Modelling studies need to explore more sophisticated general concepts of socio-economic networks, including that of ‘supracriticality’ as a function of network size and connectivity (Kauffmann, 1995), and the idea that wide-ranging networks of many ‘weak ties’ facilitate transfer of information, the diffusion of innovation, and ultimately promotes economic development, while limited networks of strong ties lead to economic stagnation (Granovetter, 1973, Granovetter, 1995).

3. Contribution to LTSER from the social sciences

3.1. Coping with diversity: a plethora of social science paradigms

Classical LTER, if it considers social factors at all, is dominated by paradigms and concepts of society, or humans, which have been developed by natural scientists. LTSER not only implies the need to consider human interventions into ecosystems, but to acknowledge that socio-economic dimensions of environmental change cannot be adequately understood without integrating researchers from the social sciences. This owes to the fact that changes in biodiversity and ecosystems are determined to a large extent by human activities, which cannot be grasped without this expertise (Delbaere, 2005).

One feature that characterizes social sciences is the heterogeneity of paradigms and theories. Selecting an approach that is useful for LTSER, requires that social scientists understand the questions asked, and problems faced, and paradigms applied in ecological research. The concepts selected must be compatible with natural scientific reasoning, they must explain social processes without denying biophysical processes, and they must open points of contact to which natural sciences can connect and relate. That is, society must neither be seen as “just one additional component” or subsystem of ecosystems, nor is it useful to conceptualize humans as a mere disturbance to otherwise well functioning ecosystems.

At the same time, social scientists have to accept that society is related to, even dependent on, ecosystems, a notion that seems hard to swallow for social scientists since the work of Max Weber and Emile Durkheim (Catton, Jr., 2002). The basic existence of society as an entity comprising biophysical structures, as discussed above, implies that it is dependent on, and in this sense part of and influenced by, natural processes (Dunlap and Catton, Jr., 1994). Society would not exist without human organisms and their capacity for reproduction and without being able to organize all the other biophysical flows (its socio-economic metabolism) required to maintaining its integrity. Society can, however, not be understood merely by observing its biophysical structures. In the social sciences, the most common usage of the term ‘society’ refers to a functional and delineated social unit that shares common cultural traits as well as to a politico-administrative unit in which decision-making and executive powers are applied (Weisz et al., 2001).

This requires another, qualitatively different, system to be taken into account, namely the purely symbolic system of recursive communication (Luhmann, 1986, Luhmann, 1995). This system is immaterial, and it is autopoietic, that is, it is self-referential and is able to structure itself and create dynamics endogenously (Varela et al., 1974). We do not follow Luhmann, however, in denoting this system of recursive communication as society, because this would deprive society of all biophysical components – a notion of society obviously not very useful to understand society-nature interaction. Rather, we adopt the notion of society as a hybrid of this system of recursive communication and a part of the material world denoted here (Figure 1) as "biophysical structures of society" (Fischer-Kowalski and Weisz, 1999, Weisz et al., 2001). "Culture" consists of both material components or artefacts, such as religious objects, tools, machinery, infrastructure, etc., and "immaterial" or symbolic elements such as beliefs, arts, knowledge, languages, etc.

Similarly, the notion of "economy" gains a double meaning: in its symbolic representation, it may be thought of as the communicative processes involved in organizing production and consumption – in industrial society the communicative subsystem delineated by the communicative code of money (almost the only set of issues addressed by professional economists today) – on a biophysical level it can be understood as the organization of the biophysical flows required to sustain a society's biophysical structures, i.e., humans, livestock and artefacts. Obviously, then, human and animal labour and artefacts required for production ("capital") are important in this context.

A third important theme is the study of governance (Ostrom, 1996). In order to support a transition toward sustainability, LTSER explores decision-making processes at different scales to understand conflict as a basis for reconciling divergent goals amongst stakeholders (Adams et al., 2003, Dietz et al., 2003), and to reduce the vulnerability of people, places, and ecosystems (Turner et al., 2003). Within LTSER, good governance is understood as the combined effort of society to implement and enforce rules related to the provision of individual and collective goods and services to sustain local livelihoods without compromising ecosystem health. This requires understanding of how access to, use, and exchange of resources are managed and negotiated in practice, questions obviously necessitating the inclusion of stakeholders in the research process.

This discussion reveals at least three entry points for social sciences that will be discussed in the remainder of this section: (a) The analysis of culture, both in its biophysical and its symbolic meaning. Here we can build on a tradition sometimes referred to as "ecological anthropology" (e.g., Orlove, 1980) or "cultural ecology" (e.g., Steward, 1955, White, 1959) that has yielded a rich body of studies of society-nature interaction (e.g., Boserup, 1965, Grünbühel et al., 2003, Netting, 1993, Singh, 2003). (b) The analysis of the interplay of the economy and ecosystems, a field of expertise today mostly referred to as "ecological economics" (Costanza et al., 1998, Martinez-Alier(ed.), 1990). An aspect that may be particularly valuable at local and regional scales that play an important role in LTSER is the focus on the interrelations between time use, land use, and income generation (Schandl and Grünbühel, 2005). (c) A focus on governance involving the participation of stakeholders and their influence in decision making (Hare and Pahl-Wostl, 2002, Pahl-Wostl, 2002, Kasemir et al., 2003). A final subsection will discuss how these concepts can be integrated with approaches from the natural sciences in innovative modeling tools.

3.2 Building on the rich tradition of ecological anthropology

In social and cultural anthropology, stress on the ecological dimension in the study of social and cultural systems is relatively recent and came about as a consequence of increasing interest in ecosystem research within biological ecology. Ecological anthropology, or an ecosystem approach to anthropology, focuses on the study of complex relations between people and their environments. In other words, it is a study of the relations among population dynamics, social organisation, culture of human populations and the environment they inhabit from both synchronic and diachronic perspectives (Orlove, 1980). Practitioners of this discipline direct their attention to an understanding of the ways by which a particular population, intentionally or unintentionally, shapes its environment, and is shaped by it (Barnard and Spencer, 1996). Ecological anthropology draws much from the systems theory approach, whereby human populations are regarded as one of the components of the ecosystem. In its most classic sense, ecological anthropology promulgated the study of energy flows between the human and the ecosystem, in particular the energetic return upon investment, and as such, interpreting cultural behaviours and subsistence patterns (Rappaport, 1967, Rappaport, 1971).

An important research agenda in treating human populations as part of ecosystems has been to understand human adaptability to various forms of environmental stress – physiological, cultural and behavioural. In doing so, there has been increasing interest in using ecological anthropology as a strategy for studying a wide range of human responses to environmental problems, to social constraints, and to past solutions to environmental problems (Vayda and MacKay, 1977). Studies relate to the various ways populations have responded to environmental forces, such as high levels of frost in highland New Guinea (Wadell, 1975), storms (Bayliss-Smith, 1974), droughts (Lees, 1974, Reyna, 1975), famines (Krech, 1978, Orlove and Custtred, 1980), and earthquakes (Oliver-Smith, 1977).

Several studies in ecological anthropology emphasise the “long-term” aspect by which mechanisms of change can be understood. This relates to the idea of “transition” as discussed earlier in this paper. Ecological anthropologists have carried out several studies to highlight the various drivers and initial conditions that may be attributed to changes in the socio-ecological system. Prominent among them are: an examination of demographic variables and production systems (Boserup, 1965), the response of populations to sudden or prolonged environmental stress (see previous paragraph), the formation and consolidation of adaptive strategies (Bennett, 1976, Bettinger, 1978), and response to globalisation of economic and production processes (Friedman, 1974).

A major influence on long-term studies has been the development of decision-making models (or actor-based models). These models permit better analysis of the parameters of behaviour and variations of behaviour within the different human populations, including conflict and competition and an understanding of the processes which generate economic, political and social relations. Decision-making models may either be cognitive / naturalistic or microeconomic models. The former borrows much from cognitive anthropology that depicts actual psychological processes of decision making by locating alternatives and the procedures for choosing among them, while the latter resemble economic models of choice making under a set of resource constraints (Orlove, 1980).

For LTSER, the field of ecological anthropology appears to be quite promising insofar as it allows a wide range of studies and methods to be harnessed, providing insights into the ways humans interact with their environment. In particular, we are able to gain from long-term studies relating to how populations have transformed their environment and how they have been transformed as a consequence. These relate to an understanding of socio-economic drivers of environmental change within the framework of LTSER. Ecological anthropology also provides insights on human decision-making and the choices they possibly would make under given resource constraints and opportunities. At the same time, the global environmental change community can enhance its understanding on the ways human populations respond to various forms of environmental stress, which in turn may provide valuable insights on possible human responses to ongoing global environmental change.

3.3 Relating time, land, and income: applying concepts from ecological economics to the local level

Ecological economics studies the relations between the economy and the environment in order to address questions of sustainability using a variety of methods (Martinez-Alier, 1987). One specifically useful approach for LTSER is the analysis of the interrelations between time use, land use, and income at the local and regional levels (e.g., Schandl and Grünbühel, 2005). In linking time use, land use, and income generation we start with the so called 'magic triangle of sustainability' (Fischer-Kowalski, 1997a) on a local level. Looking at the 'magic triangle of sustainability' we identify three dimensions along which a social unit can be analysed: the economic, the social and the ecological dimension. On a local level the ecological dimension might be defined as the way land is used in a specific area. The social dimension might be defined as the way and quality of life of a specific social unit in a specific area. Our main indicator to describe the way/quality of life is the way time is used ('time use') by the members of the social unit. The economic dimension might be defined as the monetary income of a specific social unit (household, person, community) in a specific area. The three dimensions are highly interdependent (Figure 2).

[Insert Figure 2]

We start with the interplay between land use and time use, given the condition that the system is closed in regard to available working hours. For example, at the local level, a village would comprise of a fix amount of land ("total available land") and a certain amount of time ("total available time") depending on the number of inhabitants. Of the total available land, only part is available for income generation (part may be required, for example, for living space and ecosystem services). Similarly, the "disposable human time" is only a part of the total time available since every individual requires a certain amount of time for "basic personal reproduction" (such as sleeping and eating) and "extended personal reproduction" (such as education and leisure. In this way, both land and time are a biophysical constraint. A specific way of using land requires a specific amount of working hours and vice versa. As land use requires working hours, it constrains the time budget that can be used for other activities not related to land use (leisure time, reproduction, etc.).

Similarly, land and income constrain each other. This is to say that each square meter of land is able to generate a certain amount of income. In other words, income is constrained by the quality and quantity of land available. The income on the other side determines how the land is used: if there is a need for more income, it may be that more land, if available, will be brought under production or the use of existing land is intensified. Furthermore, the quality of land use relates to the means of production or available technology a social unit can afford (such as tillers and tractors).

Similarly, the relation between time use and income can also be determined. The disposable working time in a given society is determined by several factors such as the total number of inhabitants, life expectancy, dependency ratio, and working age. This may vary by culture and region. The disposable working time has a direct bearing on the amount of money an individual can earn. Alternatively, the need for less income would mean less working hours required, and the need for a higher income may restrict time to be invested in other activities such as leisure and vacations.

All three dimensions have their inherent dynamics as they are subject to specific systems dynamics. This is to say, how time is used largely depends on the social/cultural system a social unit is part of (e.g. social values and norms, infrastructure). The income is highly dependent on the dynamics of economic systems (market, prices, etc.). Finally, land use is constrained by the specific features of the local ecosystem (e.g. rice does not grow in arid areas) as well as on global environmental dynamics. As research shows, these considerations are especially applicable in rural areas and farming systems. Several ongoing studies are now integrating land-time-income analysis within computer models such as agent-based modelling (Gaube et al., 2005). It would have to be proved how and if they apply to industrial areas. LTSER sites can be used as test areas for undertaking land-time-income analysis so as to provide insights into these biophysical constraints and opportunities in relation to possible economic options and ecological impacts.

3.4 Participation and decision making

It has repeatedly been argued in this paper that sustainability research cannot solely focus on ecosystems, but has to analyse social parameters as well. However, in most cases analysing social parameters is not enough to enable us to set powerful interventions counteracting a decrease of biodiversity levels or the quality of ecosystems. What is needed is a specific method of analysis - an analysis that allows actors to participate throughout the whole research process, starting with defining the problem that should be analysed and ending with planning or initialising specific interventions. In other words, social actors or social systems should be able to learn throughout the research process or should at least be stimulated in some way. Participation is the key to achieve this (see for example Hare and Pahl-Wostl, 2002, Pahl-Wostl, 2002).

The term participation can be defined as awareness of and identification with the research conducted in a particular locale as well as active dialog with the researchers and stakeholders with respect to the process. Research should take place with the inclusion of the relevant stakeholders in a social system, integrating their interests and defining common research goals. The classical research approach starts out with a research question, which the researcher defines according to the current state-of-the-art and its research demands. Participatory research means defining the research question and the scientific interest together with relevant stakeholders. In order to be able to do this, the area where the study is being conducted must be known to the researchers and the actors/stakeholders identified.

Stakeholders are actors that are directly involved in the problem to be investigated. After having defined the actors in the field, the group of stakeholders who will be engaged in the process may have to be narrowed down for practical reasons. While the selected group of stakeholders should bear some relevance to the problem, it is up to the researcher to lay down the criteria of selection as long as the criteria are transparent and potentially subject to criticism. In most cases, the selection criteria for stakeholders highly depend on the needs of the actors involved, the willingness to cooperate and the level of influence they wield in guiding social processes in the study area.

Research questions and goals are defined in cooperation with the stakeholder group in order to make practical use of the research results. Nevertheless, social goals and visions of the future must be translated into scientific categories and variables for their usefulness in the research process, i.e. they have to be scientifically operationalized. In return, scientific evidence has then to be transposed into socially relevant information in order to serve as a basis for decision-making.

According to the intense cooperation with the actors, the dynamics, goals and directions participative research follows, strongly depend on the needs of the actors and on the inner dynamics of the system analysed. Thus, research design differs from classical research approaches as it has to be more flexible in various aspects (e.g. definitions of research goals, selections of actors involved, milestones planned, and methods applied). Ownership is crucial in participatory research. Research results can never be applied to local decision making if the actors are not aware of the research questions and problems addressed. The stakeholder group must (at least partly) share the motivations and interests of the researcher and appreciate the methods applied in the field. Local actors must support research activities and perceive them as a possible basis for taking decisions on their own future. Ideally, participative research contributes to democratisation and involves the citizen in public decisions of the community.

3.5 The utility of models for integrating socio-economic and ecological approaches

Because socio-ecological systems are complex, and because it is not possible to manipulate real systems experimentally, modelling can help in integrating these processes into a common framework in order to analyse the likely impacts of external drivers, both solely and in conjunction with one another. Integrated models should not only focus on the economic consequences, but also on the social and ecological outcomes. Modelling can be especially useful to integrate social science-based approaches with concepts from the natural sciences (van der Leeuw, 2004). Existing models are, however, largely unattractive in this respect, as most of them reflect theories and concepts developed within single scientific disciplines. Global integrated assessment models such as IMAGE, on the other hand, that were derived by coupling a large number of existing disciplinary-based “sectoral” models (Alcamo et al., 1996) are of limited applicability at local scales such as those dealt with in LTSER. A new generation of models that can deal with local situations and aim to integrate biophysical (e.g., land use) issues with socio-economic factors is currently being explored by many groups of researchers around the world (e.g., McConnell, 2001, Janssen, 2004, Matthews, 2006)

In this context, prediction loses importance as an aim of modelling. Rather, modelling is seen as a strategy for exploring how elements of socio-ecological systems traditionally described by different disciplines are related to one another, and for learning how they might be combined to arrive at a useful representation of the overall situation. Modelling may be useful to understand how the situation might unfold, thus helping researchers and stakeholders to devise ways of achieving desirable outcomes (Figure 3). This non-linear process raises interesting questions about reflexivity and its ability to introduce uncertainty in its own right; for example, a model that could predict the behaviour of the stock-market would be used by investors to alter their behaviour, but if everyone were to do this, the predictions of the model would be falsified. Should, therefore, models of socio-ecological systems contain representations of themselves in order to realistically model the behaviour of the social processes they contain?

[Insert Figure 3]

A modelling paradigm which is potentially suitable for linking the biophysical and socio-economic characteristics of a system is multi-agent simulation or agent-based modelling. Originating from the field of distributed artificial intelligence, these models consist of a number of 'intelligent' virtual agents which are sensitive to other agents and interact with both them and their environment, and can change their actions as a result of events in the process of interaction. Agents typically have only partial knowledge of the system as a whole, but a key characteristic is their ability to communicate and exchange information with each other. The behaviour of the whole system (i.e. the virtual community) depends on the aggregated individual behaviour of each agent. Agent-based modelling is dynamic as compared to traditional approaches such as linear programming, and is particularly suitable for looking at processes over time (Axtell et al., 2002, Janssen, 2004, McConnell, 2001, Pahl-Wostl, 2002).

- Reactive agents decide on actions directly on the basis of what they have sensed around them. For example, they may select a particular land use based on soil type.
- Deliberative agents are those that, for example, reflect upon alternative courses of action, and select one of them for execution, i.e. they plan. An example of this might be that, for a particular land unit, a number of land uses are possible, but one is

selected on the basis of one or more criteria, such as relative return, and/or labour availability.

- Adaptive agents change their behaviour in the light of changing circumstances, implying an element of learning – e.g. based on the performance in the past year of a particular land use, new or modified land uses are selected.
- Social agents communicate and cooperate with other agents, keeping histories of their interactions and updating their beliefs (using Bayesian updating) after observing their environment and the behaviour of other agents.

Depending on the type of agent, each will one or more of the following main components– (a) a component to manage communication with other agents, (b) a second to maintain knowledge (i.e. the agent memory), (c) a third to make decisions based on its knowledge and perception of the outside world, and (d) the fourth to perceive the outside world. Thus, triggers for action by the agent may originate from three sources – those as a result of its own internal state, those as a result of requests from other agents, and those as a result of some condition within the environment.

Validation of such models is difficult. Validation of individual components against observed data is possible and necessary, although this does not test for any errors introduced through linking them at a higher level. Two other approaches of validation are

- Accuracy in simulating a historical situation, for example, changes in commodity prices or demographic changes over a particular time period. Such an attempt at validation was made by using a model to simulate various aspects of three widely contrasting socio-economic regions, the results of which reflected current development trends in two of the regions with reasonable accuracy (Van Keulen, 1993).

- Comparing simulated results with outcomes expected by ‘experts’. Validation would be positive when, for example, patterns of knowledge transmission predicted by the model matched those observed by sociologists or development professionals.

However, as the purpose of the model is usually to explore options for effecting change in rural communities, rather than predicting them, it is perhaps more important that the structure of the model and the assumptions incorporated into it are transparent, and therefore well-documented. Provided these are known, they can provide a focus for debate, and sensitivity analysis can be carried out to determine their relative importance to the overall system.

4. Integrating ecosystems with participation and time use: A case study from the Austrian LTSER platform “Eisenwurzen”

In this section, we will present a case-study from an ongoing project in the Austrian LTSER platform “Eisenwurzen”, one of the 10 European LTSER platforms, where we implement several of the approaches discussed above. The name of the region, Eisenwurzen (“origin of the iron”), refers to its historical role as an important iron-supplying region of Europe: A few hundred years ago, about 15% of the total amount of iron produced in Europe came from that region (Gruber, 1998). The topography ranges from hilly to mountainous, and mostly belongs to the northern limestone Alps. Due to its mountainous character, the region is hardly attractive for agriculture, in particular for intensive, high-yielding mechanized agriculture. A massive reforestation resulted which is today perceived as an important challenge for the continuation of human habitation in the region. It is estimated that forests presently cover at least 80% of the area of Reichraming. Agriculture is almost exclusively based on extensive cattle rearing, and suffers from low incomes. Commuting to regional centres such as Steyr and Linz accounts for a significant proportion of gainful employment.

Within the larger region that is included in the LTSER platform is the municipality of Reichraming the area where the project is being implemented (see Figure 4). The project "LTSER Eisenwurzen" aims to develop an integrated model SERD (Simulation of Ecological Compatibility of Regional Development) to be able to simulate changes in income and workload of farmsteads as well as land use and material/substance flows. The model will consist of two modules: (1) an agent-based actor's model and a social-economic and biophysical approaches integrating stock and flow model (figure 5). Dynamics in the model will be driven by assumptions on changes in the external conditions, both socio-economic and political as well as environmental framework.

[Insert Figure 4]

The agent-based model in SERD relates different groups of actors to each other depending on their impact on land use:

(1) Primary actors: are those land-owners who affect land use change in the region directly. Important among them are the agrarian households who decide based on their knowledge, individual preferences and information about the environment and other agents how to use land. The decision-finding process of all farms is carried out along a "sustainability triangle" in which the three core sustainability dimensions (social/ecological/economic) are dynamically interlinked with each other. The social dimension is represented by time invested by inhabitants on a farm, the economic dimension by the farm's income, and the ecological dimension by land use patterns

(Figure 2). Beside farmers, the municipality, the forestry agency of Austria, the National Park Kalkalpen and some of the households and enterprises are further land users of Reichraming and hence primary actors.

(2) Secondary agents: these are groups of actors that have a direct impact on the primary agents as they set their framework conditions e.g. landowners who do not use their land but lease it to others.

(3) Aggregated agents: finally, there are the aggregated agents such as the local government, associations and networks who have influence on the region.

[Insert Figure 5]

An integral part of the project is the inclusion of the agents / stakeholders in the research process. Workshops will be organised where assumptions for the model will be discussed at all stages of the project. The actor model will be coupled with a social/economic/ecological material/substance flow model. Outputs of the agent-based model concerning changes in land-use and agricultural practices as well as in population and infrastructure are simultaneously inputs for the integrated stock-flow module of SERD which are further divided into two types of stocks and flows. On the one hand there is the socio-economic information about humans, livestock and artefacts, and on the other hand there are ecological stocks and flows from various land categories such as forests, grasslands and cropland. Substance flows, especially carbon and nitrogen flows are sensitive indicators for changes of relevant ecological processes and allow assessments on the ecological compatibility of changes in agricultural practices, land use, economic and social conditions.

The model outputs of SERD can be classified into four parts:

1. Assessment of social and economic trends
2. Illustration of expectable land use patterns in the future
3. Changes of ecological indicators, and,
4. Changes of local and regional substance flows

SERD will allow the simulation of future scenarios, e.g. on the effects of improved collaboration between agriculture, tourism and the National Park, on the income and time use of farmsteads as well as land use patterns and substance flows. A second application of SERD will be its ability to back-cast based on historical sources and data.

5. Conclusions

Integrating socio-economic dimensions into long-term ecological research is a challenging and ongoing endeavour. It requires fundamentally new, inter-and-transdisciplinary scientific approaches. This is difficult due to the long-standing history of specialization in natural sciences, social sciences, and the humanities (Huber, 1989, p. 67, own translation): "The very idea to transcend the division between natural and social sciences (…) does not seem adequate. It is not possible to make the thick branches of a tree ungrown. (…) It would be no minor achievement if people on both sides would cease to believe to be closer to reality or to truth than the others. (…) We should strive (…) for a state of peaceful coexistence and, on the basis of this (…), create a controlled external trade that benefits both sides, hoping this could lead to some kind of co-evolution."

Exploring integrated approaches to grapple with socio-ecological systems requires both conceptual, theoretical discussions such as those included in sections 2 and 3 of this paper, and practical work in interdisciplinary case studies such as the Lower Danube Wetland

System mentioned in the Introduction and the Austrian LTSER study discussed in section 4. On a theoretical level, we suggest that the concepts of socio-ecological metabolism, transition concepts from the social sciences, and theories of complex adaptive systems can be combined to provide a good basis for integrating approaches from natural sciences, social sciences and the humanities.

On a practical level we suggest that concrete, interdisciplinary studies should be launched to be carried out at the emerging LTSER platforms with the explicit aim to test different approaches for inter- and transdisciplinary integration. In particular, we feel that the following considerations could be helpful in this context:

- Transdisciplinarity – that is, the integration of stakeholders in the research process – is a useful tool to foster problem-oriented work. Challenging interdisciplinary teams to work in a problem-oriented way is useful to help in overcoming traditional boundaries between scientific disciplines. It helps in structuring research questions in novel ways, thus inspiring innovation in interdisciplinary projects. It also requires a high level of self-reflection of the researchers, as they themselves become part of the system to be analyzed. On the other hand, high standards of scientific excellence in such projects are essential in order to prevent them from becoming purely consultancy work.
- The use of models either formalized or heuristic, is an important tool to foster interdisciplinary integration. Even though socio-ecological systems may be too complex to ever be adequately represented, let alone predicted, by formal models, the very process of constructing the model is of great help in fostering mutual learning in interdisciplinary teams (van der Leeuw, 2004). Moreover, these models can be used in

transdisciplinary processes together with stakeholders and help to structure discussions on policy options to support sustainability.

One scientific paper, such as this one, can not, of course, address all the challenges involved in designing LTSER. Other papers have focused on the situation in the United States (Redman et al., 2004) and on themes of LTSER (Haberl et al., 2006). Several groups within ALTER-Net are working on complementary projects tackling issues such as those related to scales and levels of socio-ecological systems (Dirnböck, *pers. comm.*) and on the utility of combining approaches from Political Ecology, Ecological Economics and Social Ecology in understanding drivers of biodiversity (Waetzold, *pers. comm.*). This multitude of approaches is certainly warranted, given the complexity of the problem at hand. We urgently require ever more cases where integrative approaches are tried and tested by interdisciplinary teams in order to foster mutual learning to address the sustainability issue.

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Figure captions

Figure 1. A conceptual model of society-nature interaction (based on Boyden, 1992, Fischer-Kowalski and Haberl, 1997, Fischer-Kowalski et al., 1997, Haberl et al., 2004, Sieferle, 1997) used here as a basis for conceptualising Long Term Socio-ecological Research (LTSER)

Figure 2. Basic interrelations between time use, land use and income assumed in the internal structure of agricultural agents (= farms).

Figure 3. Schematic representation of the use of models in a participatory process. Modified after Berger, 2004.

Figure 4. Location of the study area. Reichraming (marked black) is one of the 91 municipalities belonging to the LTSER platform “Eisenwurzen” which includes parts of the territory of three Austrian provinces, Oberösterreich (“Upper Austria”), Niederösterreich (“Lower Austria”) and Steiermark (“Styria”).

Figure 5. Concept of the integrated system model SERD

Figures

Fig. 1

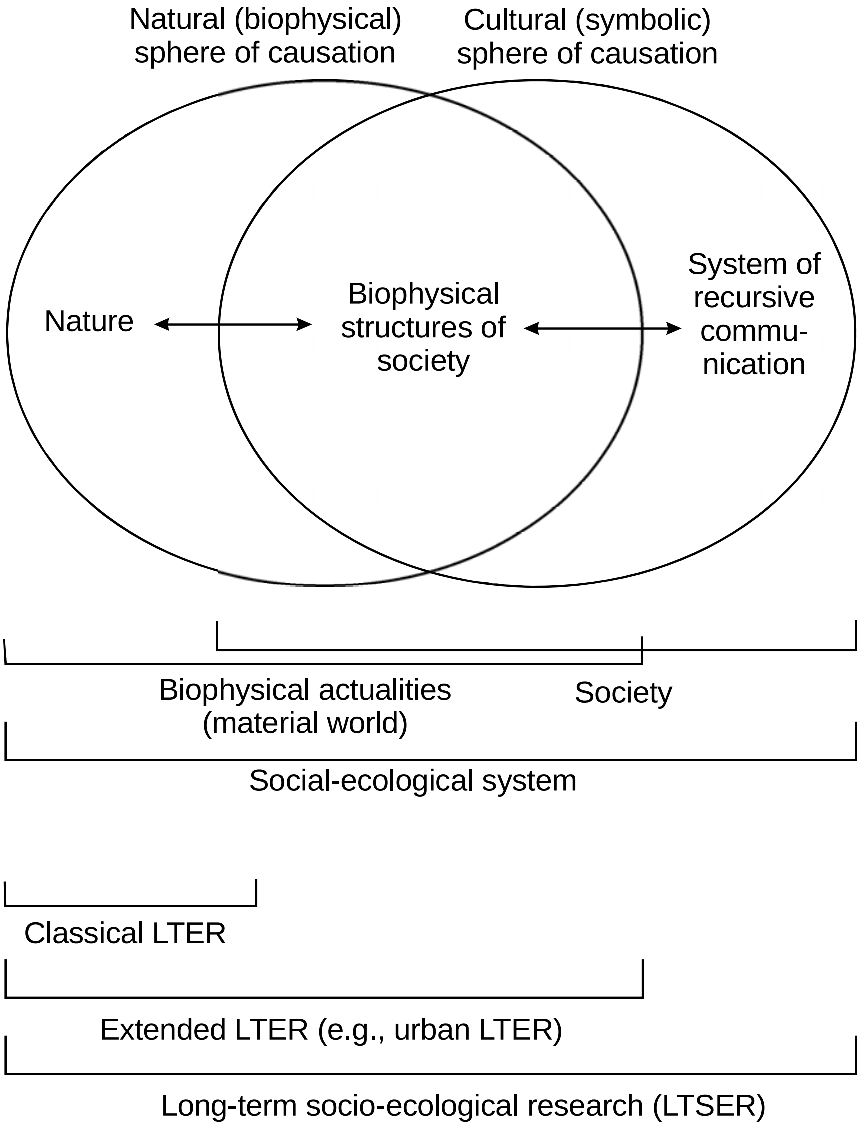


Fig. 2

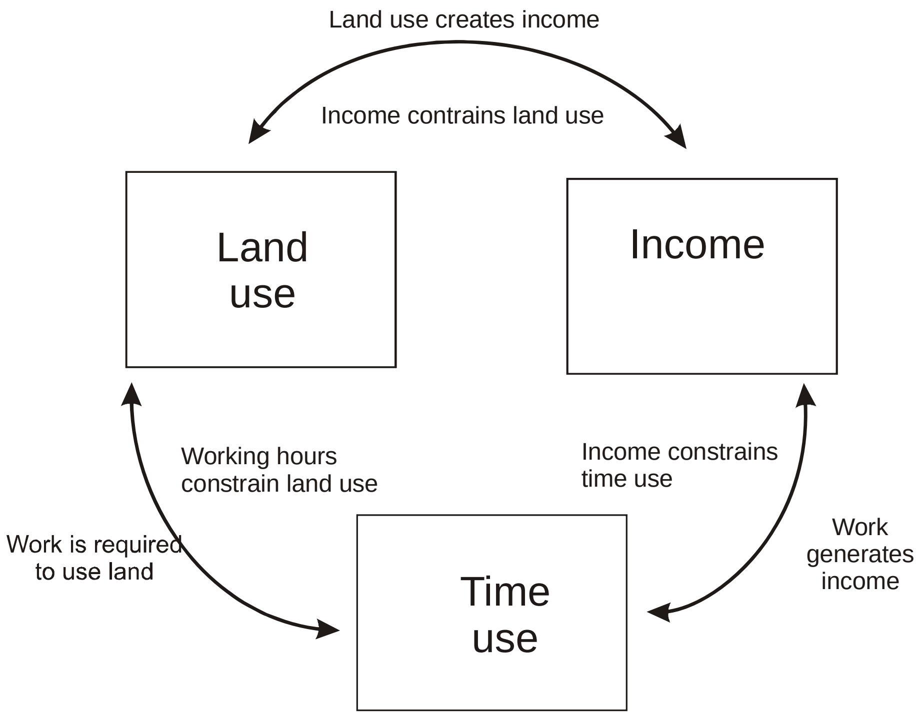

Land use creates income
Income contrains land use
Land use
Income
Working hours constrain land use
Income constrains time use
Work is required to use land
Time use
Work generates income

Fig 3.

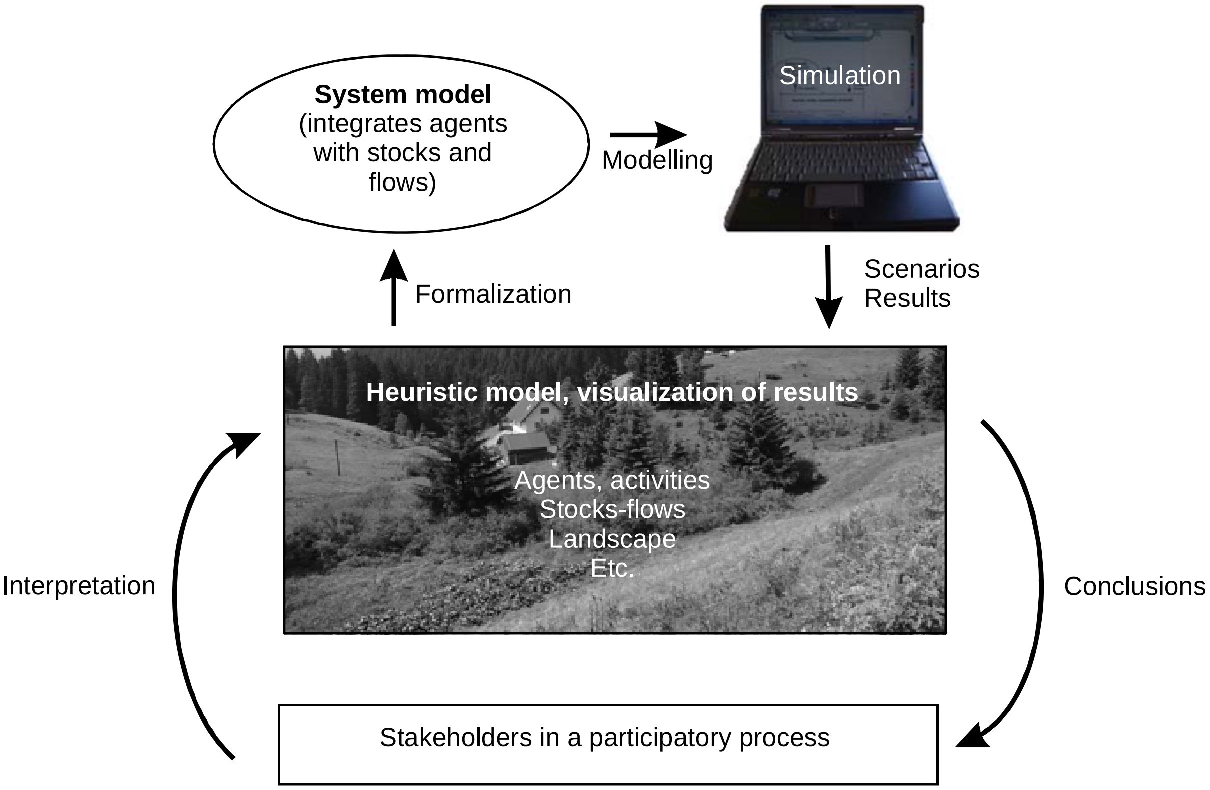

System model
(integrates agents with stocks and flows)
Modelling
Simulation
Formalization
Scenarios
Results
Heuristic model, visualization of results
Agents, activities
Stocks-flows
Landscape
Etc.
Interpretation
Conclusions
Stakeholders in a participatory process

Fig. 4

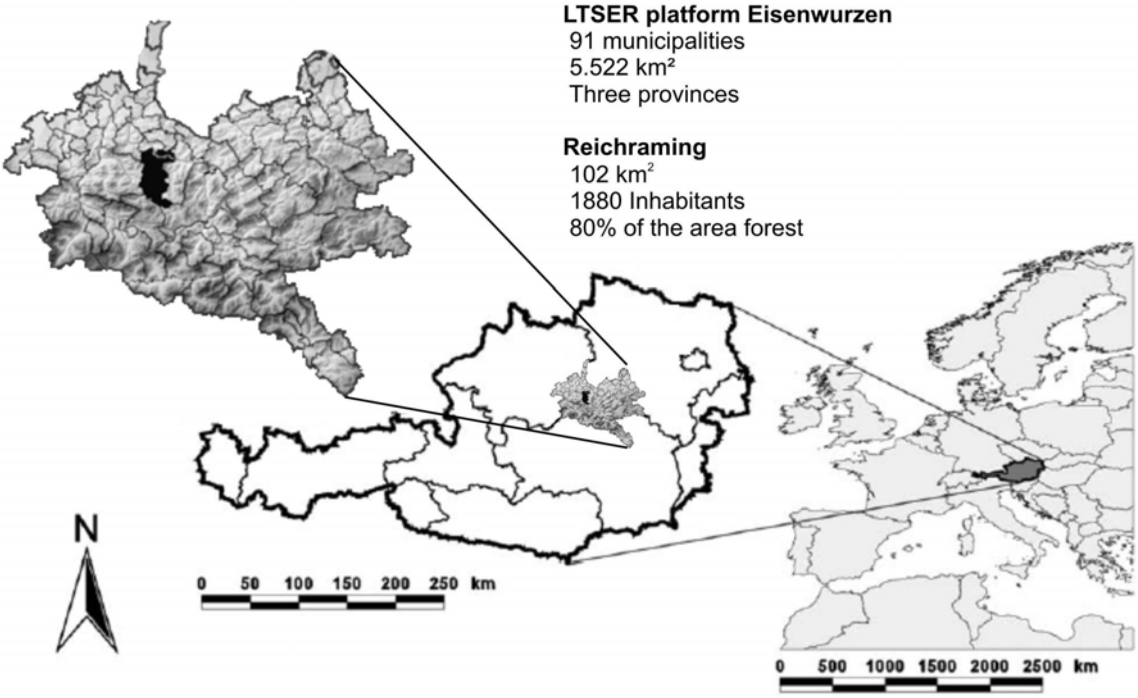
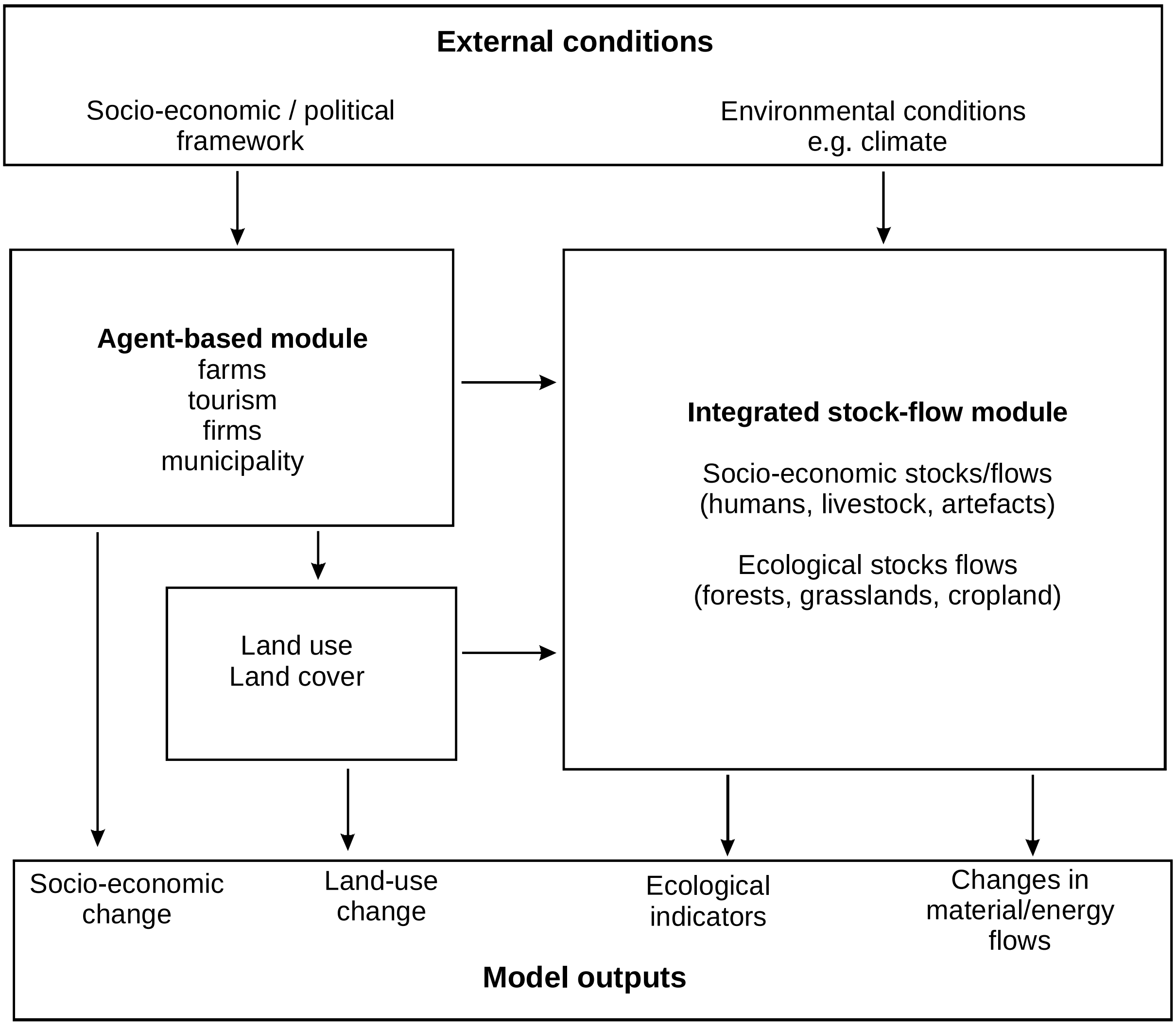

LTSER platform Eisenwurzen
91 municipalities
5.522 km²
Three provinces
Reichraming
102 km²
1880 Inhabitants
80% of the area forest
N
0 50 100 150 200 250 km
0 500 1000 1500 2000 2500 km

Fig. 5


External conditions
Socio-economic / political framework
Environmental conditions e.g. climate
Agent-based module
farms
tourism
firms
municipality
Integrated stock-flow module
Socio-economic stocks/flows (humans, livestock, artefacts)
Ecological stocks flows (forests, grasslands, cropland)
Land use
Land cover
Socio-economic change
Land-use change
Ecological indicators
Changes in material/energy flows
Model outputs