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Relating the Philosophy and Practice of Ecological Economics.

The Role of Concepts, Models, and Case Studies in Inter- and Transdisciplinary Sustainability Research

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Abstract

We develop a comprehensive multi-level approach to ecological economics (*CML-approach*) which integrates philosophical considerations on the foundations of ecological economics with an adequate operationalization. We argue that the subject matter and aims of ecological economics require a specific combination of inter- and transdisciplinary research, and discuss the epistemological position on which this approach is based. In accordance with this understanding of inter- and transdisciplinarity and the underlying epistemological position, we develop an operationalization which comprises simultaneous analysis on three levels of abstraction: concepts, models and case studies. We explain these levels in detail, and, in particular, deduce our way of *generic modeling* in this context. Finally, we illustrate the CML-approach and demonstrate its fruitfulness by the example of the sustainable management of semi-arid rangelands.

Keywords: ecological economics, interdisciplinarity, philosophy of science, transdisciplinarity

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1 Introduction

While there exists a widely shared consensus about the subject matter and aims of ecological economics (EE), the field is characterized by a vast diversity and heterogeneity of seemingly unrelated approaches and contributions (Røpke 2005). For example, a survey of the journal *Ecological Economics* reveals the extent of heterogeneity in different dimensions: (i) There is a wide spectrum of methodological approaches, including controlled experimental work, case studies, models, theories, conceptual foundation, and philosophical reflection. (ii) Some contributions aim at positive analysis in the spirit of the natural sciences, i.e. describing facts and providing explanations, while others aim at normative, i.e. value based, policy recommendations. (iii) As far as motivation goes, there is the full range between purely cognitive interest, i.e. a science-immanent motivation to study questions from science and provide answers for science, and interest in practical action and solution, i.e. a motivation to link science and society at large. This heterogeneity of approaches and contributions seems to stand unrelated and, at times, is seen as an obstacle for progress of the field.

In this paper, we develop an approach to ecological economics which integrates philosophical considerations on the foundations of EE with operationalization. We philosophically deduce the methodology of this approach and give an example for its application. Our aim is to lay out a systematic and coherent methodological framework for ecological economics, ranging all the way from basic philosophy of science to concrete operationalization. This provides a systematic view on ecological economics, and thus allows one to see the relationship between contributions to the field that have so far been perceived as very heterogeneous and largely unrelated. At the same time, the approach may provide orientation for the further development of EE.

We start with the definition of ecological economics and clarify its subject matter and aims. Based on these considerations, we reflect on the question of how to do ecological economics. We argue that the subject matter and aims of ecological economics require a specific kind of inter- and transdisciplinary research. Furthermore, we reflect on the adequate epistemological basis for EE, referring to considerations within the philosophy of science. In accordance with the philosophical considerations on the foundations of EE, we develop an adequate operationalization, which comprises simultaneous analysis on three levels of abstraction: (i) the level of concepts (ii) the level of models and (iii) the level of concrete case studies.

The integration of considerations on the philosophy of EE – its inter- and transdisciplinary character and its epistemological foundation – with a concrete operationalization by simultaneous analysis on three levels of abstraction – concepts, modeling and case studies – we call comprehensive multi-level approach to ecological economics (*CML-approach*).

Finally, we illustrate this approach by the example of an analysis of the sustainable management of semi-arid rangelands, which combines ecology, economics and philosophy. This illustration demonstrates the operationalizability and fruitfulness of the approach.

2 Ecological economics: subject matter and aims

Our starting point is the question (discussed in this Section): What is ecological economics? From the answer to this question we will deduce (in Section 3) the answer to a second question: How to do ecological economics? This means that in defining EE we give priority to the subject matter and aims of EE. From this, its approach and methods are derived in a second step. This is in contrast, for example, to mainstream economics which is often defined purely by its methods (Robbins 1935, Kirchgässner 2000). Our proceeding is in accordance with the origins of EE, as well as with the current shared belief of the scientists in this community. In both, EE has primarily been defined by its subject matter and aims, and on this basis it has been discussed which were the appropriate methods and approaches for EE (Proops 1989; Costanza 1991; Krishnan et al. 1995; Faber et al. 1996).

There are two central characteristics of EE. First, there is a fundamental consensus that EE aims to “study how ecosystems and economic activity interrelate” (Proops 1989: 60). Thus, the subject matter of EE is the “relationship between ecosystems and economic systems in the broadest sense” (Costanza 1989: 1). However, the aim of EE has never been a merely functional and descriptive analysis of this relationship. Within EE, the question has always been raised how this relationship can be organized in a sustainable manner. Thus, the second characterization of EE is that it understands itself as “the science and management of sustainability” (Costanza 1991). This means in particular that EE is not only driven by a *cognitive* interest, i.e. an interest to understand and explain the world as it is, but also by an *action* interest, i.e. an interest to manage the world based on an idea of how it ought to be.

There is an ongoing, broad and diverse discussion about how exactly to define, conceptualize and measure *sustainability* (surveyed e.g. by Pezzey 1992, Heal 1998, Klauer 1999, Neumayer 2003), reflecting the breadth and diversity of ideas about (i) what exactly is the normative content of sustainability and (ii) how exactly can the structure and functioning of ecological-economic systems be described. The shared consensus in this discussion seems to be that sustainability – by any definition of the concept – requires sustaining nature, and its functioning and services for humans, over a long time into the future. This has implications for how socio-economic systems and their relationships with nature must be organized.

In summary, the subject matter of EE is the relationship between the economic and the ecological system, and its underlying central aim is to provide knowledge for a sustainable management of this relationship.

3 Methodological implications: ecological economics is an inter- and transdisciplinary science

From the definition of ecological economics (Section 2) it follows in a straightforward way that EE is an inter- and transdisciplinary form of science, where *interdisciplinarity* is broadly understood as some kind of cooperation between scientific disciplines, and *transdisciplinarity* as some kind of interrelationship between science and society. This has been noted from the very beginning of EE (Norgaard 1989, Costanza 1991, Røpke 2005). However, there is an ongoing discussion as to what exactly means “interdisciplinarity” and “transdisciplinarity”. To obtain a fruitful and operational basis for scientific work in EE, the general concepts of interdisciplinarity and of transdisciplinarity require further clarification and specification.

3.1 Interdisciplinarity

The relationship between the ecosystem and the economic system is complex. To study this relationship in an encompassing manner several aspects have to be taken into account, including biological, physical, chemical, economic, political, social, cultural as well as ethical aspects (Costanza 1991; Faber et al. 1996; Max-Neef 2005). These are the subject matter of different scientific disciplines. Thus, the analysis of the relationship between the economic and the natural system requires the cooperation of many scientific disciplines, which is generally called *interdisciplinarity*. More specifically, different forms of interdisciplinary cooperation can be distinguished as follows (Baumgärtner and Becker 2005):

(a) A *side by side of disciplines*, in which different disciplines analyse the same subject matter, but they do so independently of each other. That is, each discipline addresses the aspects that it considers relevant, and it does so in its own terminology and based on its own set of concepts, methods and theories. This form of interdisciplinary cooperation is sometimes also called *multidisciplinarity* (Max-Neef 2005). For example, in a multidisciplinary analysis of greenhouse gas emissions by economists, legal scholars and atmospheric scientists, the economists would study the optimal allocation of emissions based on their costs and benefits; the legal scholars would study the restrictions on emissions imposed by existing, national or international, regulations; and the atmospheric scientists would study the physical or chemical impact of emissions on the state of the atmosphere. Their results would typically be reported as an additive compilation of independent disciplinary sub-reports, each written by one disciplinary sub-group. In such a multidisciplinary analysis, the different disciplinary contributions are not integrated in any substantial manner. A synopsis of the different disciplinary results remains the task of the recipient of the results.

(b) A *division of labor between disciplines*, in which different disciplines address the same subject matter in such a manner that they each base their investigation on their own disciplinary set of concepts, methods and theories. The results will be exchanged via clearly defined data interfaces, or will be fed as input in a subsequent integrative analysis such as e.g. multi-criteria decision analysis. This may be a recursive procedure. In this understanding of interdisciplinarity, the coordination and cooperation of disciplines pertains to the input and output of data and results; it does not cover the internal elements and structure of the disciplinary analyses. It does not touch upon the disciplinary research process itself, e.g. methods, theories or concepts. An example is the interdisciplinary analysis of global anthropogenic climate change by coupled simulation models, where demographic and economic models produce projections about future emission paths; these serve as input into climate models, which predict climate change; and the climate data thus obtained are then, again, fed into the economic models of optimal emission choice.

(c) While in an interdisciplinary division of labor each discipline retains autonomy over how to set up and carry out its analysis, a closer coordination and cooperation is possible. In a *fully integrated cooperation of disciplines* the concepts, methods and theories of the disciplines involved are closely related and adjusted to each other with regard to the joint interdisciplinary scientific aims and subject matter. This happens in a discussion process among scientists that clarifies what disciplinary concepts, methods and theories are adequate to the joint interdisciplinary endeavor, how they relate to each other, and how they need to be adjusted to each other with regard to the interdisciplinary scientific aims and subject matter. This form of fully integrated interdisciplinary cooperation hence requires from all scientists the ability to transcend the boundaries of their own discipline. An example is the ecological-economic analysis of management of semi-arid rangelands presented in detail in Section 6 below.

While one can find all forms of interdisciplinary research described above within EE, a fully integrated interdisciplinary cooperation is most appropriate to EE. EE is primarily defined by a new and complex subject matter – the relationship between ecosystems and economic systems in the broadest sense – and requires appropriate concepts and methods. A simple (side by side or division of labor) combination of disciplinary concepts and methods which were originally adapted to specific disciplinary subject matters and aims certainly reaches too short. If, for example, combined effects of ecological and economic factors or dynamic feedback loops between the systems are important, a fully integrated interdisciplinary cooperation is indispensable. Developing appropriate concepts and methods for EE requires an explicit reflection of adequate modification and integration of disciplinary concepts and methods with regard to its scientific aims and subject matter. It therefore requires a form of interdisciplinarity that explicitly includes such reflection. In other words, EE requires a fully integrated interdisciplinary cooperation.

3.2 Transdisciplinarity

Concerning the aim of being “the science and management of sustainability”, EE has to reach out beyond science to include aspects of practical contexts and to feed back results to practical actions. The management of sustainability requires the interconnection between EE as a science and society. Sustainable solutions have to be developed in the context of concrete environments and societies. This interconnection of science and society is generally called *transdisciplinarity* (Novotny 1997, Lubchenco 1998, Thompson Klein et al. 2001, Hirsch Hadorn 2002, Hirsch Hadorn et al. 2006).[1]

As far as the transdisciplinarity of EE is concerned, there are two particular challenges that arise from the definition of EE as the science and management of sustainability.

(a) In order to develop analyses and solutions for practical problems, the science of EE needs *factual knowledge* about the systems and problems it studies. To some extent, this requires cooperation beyond the boundaries of science, e.g. with stakeholders or practitioners possessing non-scientific knowledge, such as person-based tacit knowledge (“know-how”). The discourse with, and participation of, such societal actors and groups can help to identify relevant research questions and conceptual structures of the problem under study. Later on, it can facilitate the adoption and implementation of solutions. Finally, it provides the detailed knowledge about facts and cause-effect mechanisms that goes into scientific analysis. An example is the search for, and sustainable management of, pharmaceutical substances embedded in the naturally occurring biodiversity. This endeavor brings together academic scientists – such as biologists, chemists and physiologists – and indigenous people with their traditional knowledge about the medicinal impact of local plants.

(b) As EE aims to analyse conditions and ways for a sustainable development, it also needs to deal with *values and normative judgments* (Hirsch Hadorn et al. 2006). For what is sustainable development depends – besides objective properties of the system to be studied – on valuations and norms. For example, one has to specify what should be sustained and to what extent, and – ultimately – for what reasons. Should we conserve the blue whale, in what number, and for how long? And for what reason? Because of its direct or indirect value to currently living generations, or because of intergenerational fairness to future generations, or because the blue whale has an own right of existence?

    Thus, sustainability includes essentially an ethical dimension, which is the subject matter of descriptive and normative ethics. Such sustainability ethics encompasses at least three aspects: The moral relationship between humans and (i) other currently living humans, (ii) future generations of humans, and (iii) non-human nature. The science and management of sustainability therefore requires a reference to valuations in society (descriptive ethics)[2] and to moral philosophy (normative ethics). One particular challenge of transdisciplinarity in EE is how to include, and how to deal with, the complex ethical issues raised by the imperative of sustainability.[3]

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[1] Within EE, there is no precise use and understanding of the term “transdisciplinarity”. There are several definitions (Costanza et al. 1998, Ch. 3; Max-Neef 2005, Røpke 2005; Hirsch Hadorn et al. 2006). Some understand “transdisciplinarity” as a kind of interdisciplinarity (e.g. Costanza et al. 1998).

[2] The descriptive analysis of values can benefit from an interdisciplinary cooperation with disciplines such as sociology, political studies or ethnology.

[3] One has also to consider that science itself is based on normative assumptions and contains valuations. E.g., values and norms enter science as the personal, subjective values and norms of each individual scientist who decides – based on theses values – about what issues and topics to address, what problems to study and what questions to ask, what examples and illustrations to choose, etc. All these value-based individual decisions have an impact on the state and progress of science. In the transdisciplinary relationship between science and society this issue of value has to been addressed explicitly.

Both aspects (a) and (b) are essential for the specific way in which EE as a transdisciplinary science requires connection with concrete social contexts and values.[4] Transdisciplinarity means to reach out beyond science and to include aspects of practical contexts and values or normative judgements (sustainability, good-practice), as well as to feed back results into practical actions (politics, management).

4 Epistemological foundations of the CML-approach

Our analysis so far has shown that EE is a demanding and complex scientific challenge. The specific constitution of EE requires a specific epistemological foundation. In this section we sketch these crucial epistemological fundamentals on which the CML-approach is based.

It is most appropriate for EE to base itself on an epistemological position in between the two extremes of radical empiricism and pure rationalism. *Radical empiricism* holds that all human knowledge exclusively stems from experience, from the observation of a given real world (e.g. Hume [1740]2000). *Pure rationalism*, in contrast, holds that all correct human knowledge stems from the human mind (e.g. Descartes 1642). The specific inter- and transdisciplinarity of EE described above (section 3) requires both, the reference to the complexity of real-world experience and its aspects beyond pure rational construction (forms of personal knowledge, cultural values, etc.), as well as the reference to the rational construction of the mind, which turns out to be crucial in particular for interdisciplinary integration in which different concepts and approaches have to be combined. *Knowledge*, in this perspective, is the result of the interplay between human intellect and empirical experience. It is a mental construction which is inspired by experience and has to stand the test of experience.[5]

The interplay between human intellect and empirical experience may result in different forms of knowledge or constructions of reality. Most constructions have emerged over long time in a social or scientific community: they are historically, socially and culturally contingent (Gergen 1994, Schüßler and Bauerdick 1997). We call a given common construction within a certain society a *basic construction of the world*. It encompasses norms, notions and mechanisms (such as causal relationships) and represents the (human perception of the) world. It may differ from society to society and change over time, but within a society and at any point in time it is a consistent and given structure for its members.

This holds in particular for scientific knowledge. Every science provides a basic construction of (a certain aspect of) the world.[6] It has historically emerged in a scientific community and differs from community to community.[7] Within the context of a scientific community, the notions, norms and mechanisms of the respective basic construction can be used and understood by the members without further explanation. Therefore it is not necessary that every notion is explicitly and exactly defined: The meaning of most notions becomes obvious by their use within the context of the respective science.[8] For example the notion "utility" can be used within economics without further explanations or reference to an exact definition. The basic construction of a specific scientific community is a given precondition for individual

[4] This understanding of transdisciplinarity includes aspects that have been discussed within EE under the label "post-normal-science" (Funtowicz and Ravetz 1991, 1993, 1994, 2003, Tacconi 1998, Ravetz 1999, Müller 2003).

[5] In the philosophical tradition, there have been several epistemological conceptions which can be regarded to be somehow "in between" empiricism and rationalism, e.g. those due to Kant ([1781/87]1990) or Popper (1935). However, a more detailed discussion of these positions is not within the scope of this paper.

[6] Kuhn (1970) uses the term *paradigm* in a similar sense.

[7] See also the position of Lakatos (1970, 1978).

[8] See also Wittgenstein (2001: Section 43): "For a *large* class of cases […] the meaning of a word is its use in the language".

scientific work: e.g. if one develops a particular (disciplinary) model, one necessarily is within the context of the notions, mechanisms of explanation and norms of the scientific community. Individual scientific work, e.g. modeling, thus is a concrete, explicit construction which is contingent on the respective basic construction of the scientific community.

Different sciences or scientific communities have developed different basic constructions of the world, and thus are characterized by different sets of notions, norms and explanatory mechanism they use. In regard to the mechanisms, for example, economists typically explain economic outcomes as the result of rational choice by individuals (e.g. Becker 1976), while ecologists typically explain ecological outcomes as the result of evolution (see e.g. Mayer 1997). In regard to notions, the same notion may be used in a different sense in different communities (e.g. “equilibrium”, or “optimal”), because the meaning of notions depends on the basic construction they are part of.

The specificity and conditionality of different basic constructions of the world obviously poses a big challenge for fully integrated interdisciplinary research: it is a necessary precondition for such integrated research to recognize the limitations and conditionality of the different disciplinary basic constructions of the world, and it is necessary to develop a common basic construction of the world for integrated interdisciplinary research.

Understanding knowledge in the way outlined above, and recognizing the conditionality and the specificity of disciplinary scientific knowledge is crucial for a successful interdisciplinary integration, which we have deduced as being at the core of EE (Section 3.1). This is an essential epistemological prerequisite for EE in general, and the basis of the CML-approach in particular.

5 Operationalization of the CML-approach by three levels of analysis: concepts – models – case studies

The specific definition of inter- and transdisciplinarity (Section 3) and the underlying epistemological position in between empiricism and rationalism (Section 4) suggest a certain operationalization of the CML-approach to ecological economics. This operationalization proceeds simultaneously on three levels of analysis: (i) concepts, (ii) models and (iii) case studies.

5.1 Concepts

A *concept* is an intellectual figure – a norm, a notion or a mechanism – that is part of the basic construction of the world by a scientific community.

Concepts can be notions like “equilibrium”, which are used differently e.g. within economics, ecology or physics. They can be explanatory principles, like the concept of evolution in ecology or the concept of rational choice in economics. They can be norms, which distinguish a specific set of outcomes or processes, e.g. optimality or viability. Finally, they can be basic axiomatic principles a discipline is based on, e.g. the specific understanding of the human being or nature in economics and ecology. All these different concepts have implications for the disciplinary scientific analysis and its results, and they have to be recognized to fully understand the meaning and limits of the results (see e.g. Becker et al. 2005, Baumgärtner et al. 2006, Baumgärtner et al. 2006a, Becker 2006).

In particular, the whole range of concepts relevant for the subject matter of interest is crucial for any interdisciplinary and transdisciplinary cooperation. There may be congruence, complementarity or contradictions between the underlying concepts of different sciences, as well as between the underlying concepts of science and society. A successful inter- and transdisciplinary research requires an explicit reflection on the different concepts and an analysis of their relation. There has to be an appropriate adjustment of these concepts, which provide a common basis for interdisciplinary scientific work.

This requires to step back from the contexts of individual disciplines and to take a broader perspective. It requires philosophical thinking. Such philosophical expertise can be provided by the philosophical educated scientist himself, or by interdisciplinary cooperation with philosophers.

The CML-approach includes such a reflection on the concepts ecological-economic analysis and modeling are based on. Norms and notions of all disciplines involved are explicitly reflected, and congruence, complements or contradictions are analysed. As far as possible, an integrated conceptual basis for modeling and application is developed.

5.2 Models

A *model* is an abstract representation of a system under study, explicitly constructed for a certain purpose, and based on the concepts within a scientific community's basic construction of the world that are considered relevant for the purpose.[9]

Purposes of modeling can be very different. At a fundamental level, modeling-purposes may be distinguished – just like all activities within EE – according to whether they serve a cognitive interest, i.e. an interest to understand and explain the world as it is, or an action interest, i.e. an interest to manage the world based on an idea of how it ought to be (cf. Section 2). At a more detailed level, the most common purposes that models may serve include the following:[10]

1. *Theory-development*: Models may be used as tools for the heuristic development and refinement of a general theory covering a certain class of phenomena in the system under study. In particular, in the very early stages in the development of a scientific community a model may serve as a substitute for a general theory.

2. *Theory-testing*: A model may be used to test a general theory about a certain class of phenomena in the system under study. For example, a model may be used to formally verify the completeness and logical consistency of the general theory, to derive concrete empirically testable hypotheses from a general theory, or to formally test hypotheses.

3. *Generalization*: A suite of models may be used to identify and characterize the largest domain of validity of (i.e. the weakest assumptions and conditions necessary to derive) a particular statement about the system under study.

4. *Understanding*: A model may be used to better understand the "functioning" of the system under study. In particular, a model may be used to identify the consequences of changes in particular cause-effect-mechanisms and the role of particular assumptions for the set of all potential states of the system under study.

5. *Explanation*: A model may be used to identify the causes of an actual change in the state of the system under study.

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[9] See also Mäki (2002: 11) who defines a model as "a simple system used as a representation of [...] a more complex system", or Starfield et al. (1990), Baumgärtner et al. (2006a) who describe a model as a purposeful representation of a system that consists of a reduced number of (i) system elements, (ii) internal relationships between these, and (iii) relationships between system elements and the surrounding environment of the system. The specification of the system elements and their internal and external relationships determine to what extent we have a disciplinary or an integrated model and depend on the purpose of the model.

[10] This list of different purposes a model may serve is certainly not exhaustive. For more encompassing discussions of what a model is, what the role of models in science is, and what purposes a model may serve, see e.g. Suppes (1960), Freudenthal (1961), Braithwaite (1964), Bunge (1973), Leatherdale (1974), Leplin (1980), Walsh (1987), Hartmann (1995), Morgan (1998, 2002), Mäki (2001) or Sugden (2002) .

6. *Prediction*: A model may be used to identify, either qualitatively or quantitatively, the consequences of a particular change in the system under study for the future state of the system.
7. *Decision-support*: A model may be used to illustrate options and scenarios in terms of alternative future states of the system, which can then be assessed and compared by decision makers.
8. *Communication*: A model may be used to create metaphors and images that can help get a message across, e.g. from scientists or stakeholders to (other) stakeholders, decision makers etc.
9. *Teaching*: A model may be used to teach students[11] analytical techniques and allow them to gain practical experience with these techniques. Often, so-called 'toy models' are used for this purpose, i.e. simple models that are not necessarily directly relevant to the study of the system. Later on, these analytical techniques can then be applied to the analysis of more relevant, and potentially more complicated, models of the system under study.

Depending on the purpose, a model can aim at providing general insights on a very abstract level or at providing specific insights into a specific system. In the first case, it may be adequate to use simple toy-models. In the second case, however, toy-models may be too simple and it might be more fruitful to use a more specific and realistic model. This however, is often bound on the specific circumstances and characteristics of the system under study, and is not suited for applications to other cases. Thus, on the one extreme, the purpose is to generate general insight into a large class of systems; on the other extreme, the purpose is to generate very specific insights into a particular system. On the one hand, the aim may be to generate knowledge for the sake of theory building, e.g. to test hypotheses or to identify basic principles; on the other hand, the aim may be to generate knowledge for the sake of application, e.g. the management of systems or the solution of environmental problems in a specific case. On the one extreme, models are somehow an intellectual game; on the other extreme, they try to be structurally realistic and to incorporate all relevant details. This can be traced back to the extremes of epistemological positions: To rationalism, which regards human intellect as the primary source of knowledge, in the first case, and to empiricism, which holds that reality is the main source of knowledge, in the second case.

The CML-approach suggests using a form of modeling that is in between both perspectives: *generic* modeling. Generic models focus on the factors that are most essential for the purpose and ignore further details. Thus, results obtained from generic models can potentially be generalized to a large class of systems. At the same time, they retain enough structure to be actually applicable to a broad class of realistic systems. Hence, generic modeling supports both the purpose of generating general insights with the purpose of applying the model to specific cases. The combination of these two purposes allows an iterative process of reflection: a mutual inspiration between intellectual generalisations and tests of empirical application. This is in accordance with the epistemological position behind the CML-approach that knowledge ultimately is a result of the interplay between human intellect and empirical experience (Section 4). Thus, generic models represent an intermediate stage in the spectrum of empiricism and rationalism. They bridge the gap between abstract concepts and specific case studies. Hence, they ensure that model analyses are both conceptually sound and anchored in reality.[12]

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[11] Today's students are tomorrow's decision makers. Building models for teaching purposes, and teaching models, therefore, are important tasks in regard of transdisciplinarity.

[12] Using generic models implies, inter alia, that sometimes simulation techniques and analytical techniques of modeling have to be combined. Simulation models allow to refer to more real data and to include the complexity of the real case under study. Analytical models are more abstract constructions, which often

In the context of EE, fully integrated models are required that take a variety of aspects into account that are usually studied in separate disciplinary models (cf. Section 3.1). There are numerous models that explicitly consider aspects of one discipline but include aspects from the other discipline merely as exogenous condition. Such models may reach too short if combined effects or dynamic feedback loops between the ecological and the economic systems are expected (Wätzold et al. 2006). In this case, there is no alternative to the use of fully integrated ecological-economic models. Such models can be obtained by an appropriate enhancement and combination of ecological and economic model-elements. This, however, poses two specific challenges:

(1) As the different model-elements of a fully integrated model originate from the specific basic constructions of the world of the different involved disciplines, they may be based on assumptions that are not per se compatible (cf. Section 4). In this case, harmonization is needed to integrate the different model-elements. This includes referring to the basic constructions of the respective disciplines, and fully understanding the notions and mechanisms the model-elements are based on.

(2) Another challenge of integrated models is the potential increase in model complexity that may result from combining pre-existing models or model elements. As it is essential that one fully understands the functioning of the integrated model,[13] to avoid overlooking important feedback loops etc. and to recognize how specific assumptions limit the generality of the results, it may therefore be necessary to simplify some model components or the overall model structure. Fully integrated interdisciplinary models therefore do not necessarily need to be more complex than disciplinary models.

5.3 Case Studies

A *case study* is the descriptive, explorative and prospective study of a concrete real-world situation, including its practical context and its determining factors, for the purpose of generating and testing hypotheses (Eisenhardt 1989, Scholz and Tietje 2002, Yin 2002).

The reference within the CML-approach to case studies is in accordance with the epistemological position that *knowledge* is the result of the interplay between human intellect and empirical experience (cf. Section 4). Case studies are the empiricist basis within the CML-approach. A case study directly represents the real-world and practical context of models. From this context, questions and models emerge, and against this system, models and hypotheses are tested. Compared to other forms of empirical research, such as field studies or controlled laboratory experiments, case studies are not guided that much by theory and are, thus, closer to the ideal of radical empiricism.

Furthermore, the reference to case studies represents the transdisciplinary dimension of the CML-approach. On the one side, this allows to take up research questions, knowledge, norms, aims or judgements from society and to integrate them on all three levels of analysis (de-contextualization). Case studies are particularly crucial for adequately including the concept of sustainability in the transdisciplinary research framework, as this concept contains norms and value statements which cannot be developed within science alone. On the other side, case studies allow an adequate transfer of results and solutions to practical problems, as reference to a particular context facilitates re-contextualization of scientific results. This supports political decision making and management of ecological-economic systems.

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allow the identification of more general mechanisms. Thus, a combination of these techniques seems to be an adequate means for generic modeling. Yet, a challenge arises as to how to combine the different modeling techniques.

[13] Full understanding of the functioning of the integrated model is jeopardized, for example, as long as one considers some part of the model as a „black box“, the internal structure and functioning of which is left to „the other discipline“.

5.4 Interplay of Concepts, Models and Case Studies in the CML-approach

Within the CML-approach, the three levels of operationalization are strongly connected with and related to each other. This interconnection allows a successful inter- and transdisciplinary analysis of ecological-economic systems and their sustainability. In the following, we explain the relation between the levels in detail.

The reference to concepts and to case studies is due to the underlying epistemological position of the CML-approach that scientific knowledge is the result of the interplay between human intellect and empirical experience. Within the CML-approach, generic ecological-economic models function as 'mediators' (Morgan and Morrison 1999) in a specific meaning: they mediate between concepts and case studies, and, ultimately, between the rationalist and the empiricist dimension of human knowledge. The relation between the different levels is not just in one direction and for one time. The analysis on the different levels rather is mutual stimulating, controlling and correcting each other. It is a dynamic research progress of simultaneous interaction.

The analysis of concepts is a crucial prerequisite for successful interdisciplinary modeling. As models belong to the specific basic constructions of the world of every discipline, the notions and mechanisms from the different disciplines the models are based on have to be clarified and harmonized. This requires an interaction between modeling and conceptual analysis.

Sustainability research requires an adequate inclusion of the concept of sustainability. As this concept includes norms and value statements which cannot be developed within science alone, it is important to cooperate with ethics and to take up norms or judgements of social groups, to transform them into scientific concepts and to analyse which way is optimal to realize these normative aims. In the CML-approach, sustainability is taken up and formalized on the level of concepts and operationalized through modeling. Judgements about what is sustainable and working well in specific cases is taken up by referring to *good-practice* case studies, so that these judgements can then be reflected through model analysis.

The most important advantage of the CML-approach is that it provides a scientific framework for performing sustainability analyses across the three levels of operationalization. The core of the framework is the generic ecological-economic model. By developing the model in regard to a particular case study, *practical* knowledge and *normative* value judgments can be integrated in the *scientific* analytical framework. By systematic model analyses, research questions such as the following ones can be studied: Under what conditions is the management system under study sustainable? What factors are crucial for sustainability? What environmental and socio-economic conditions foster or hinder sustainability? By reflecting the answers to these questions basic principles for sustainable management of ecosystems can be derived. In addition, hypotheses regarding the interplay between ecological and economic factors can be tested and, if the need arises, modified. This provides the basis for sharpening the ecological-economic concepts involved. Evidently, the CML-approach supports both theory building in EE and decision-making in management and policy.

6 Application of the CML-approach: Sustainable management of semi-arid rangelands

In this section, we illustrate how the CML-approach works, and demonstrate that it is operational and fruitful, with the example of sustainable livestock grazing management in semi-arid areas. This is a prime object of study in ecological economics, as the ecological and economic systems are tightly coupled (e.g. Perrings 1997, Perrings and Walker 1997, 2004, Janssen et al. 2004, Quaas et al. 2007).

Semi-arid areas are characterized by low and highly variable precipitation, which drives the dynamics of the ecosystems (vegetation and livestock). Their predominant use is by livestock grazing, which provides the livelihood of almost one billion people. Grazing management strategies that are insufficiently adapted to the harsh conditions have lead to degradation at a global scale. The solution of this problem by developing sustainable grazing management strategies and corresponding institutions requires insights into the interrelations between the ecological dynamics and the economic decision making process. This is particularly urgent in face of various ongoing processes of global change (e.g. climate change, institutional change).

Understanding how sustainability of semi-arid grazing systems can be attained requires understanding of two aspects: (a) the decision processes that lead to the adoption of a particular grazing management strategy, and (b) the impacts of different grazing strategies on the dynamics and stability properties of the utilized rangeland system. The farmers' decision-making takes place in a complex ecological and economic environment which is itself shaped by the grazing activity. That is, feedback loops between the ecological and the economic system are intrinsic in semi-arid grazing systems. These feedback loops and their impacts on the dynamics and stability properties of the overall system are not fully understood so far. Hence, sustainable grazing management of semi-arid rangelands is an example for an environmental issue at the intersection between ecology and economy that requires a fully integrated inter- and transdisciplinary analysis.

We have applied the CML-approach to this problem in a series of studies – in a fully integrated interdisciplinary cooperation among ecologists, economists and philosophers – with the aim (a) to provide insights about basic principles of sustainable livestock grazing in semi-arid regions and the design of institutions for managing ecological-economic risks in this context, (b) to contribute to a further foundation of the relevant ecological-economic concepts used, and (c) to provide generic models and methods that can be used for further research (Faber et al. 2005, Frank et al. 2006, Baumgärtner 2007, Baumgärtner and Quaas 2007, Müller et al 2007, 2008, Olbrich et al 2007, Quaas et al. 2007, Quaas and Baumgärtner, in press).

Before we give examples for these three categories of results achieved through applying the CML-approach, we will briefly introduce the main components of the approach – case studies, concepts and generic models – we worked with.

6.1 Case study: Gamis farm, Namibia

In the CML-approach, case studies anchor analyses in reality and provide specific information about all components of the ecological-economic system relevant for the sustainability issue under consideration (cf. Sec. 5). In the field of semi-arid livestock grazing management, these components are the ecological conditions on the pasture, the economic situation of the farmers, and the grazing management system implemented. One example for a semi-arid grazing management system is the Gamis Farm (Frank et al. 2006, Müller et al., 2007, Quaas et al. 2007), a commercial sheep farm situated in the southwest of Namibia. Annual precipitation has a mean of below 180 mm/y and a coefficient of variation of more than 50% in this region. The vegetation is dominated by perennial grasses. Not more than 3000 Karakul sheep are kept on an area of 30,000 hectares. The primary source of revenue is from the sale of lamb pelts. Income fluctuates substantially depending on weather conditions and prices uncertainties (Olbrich et al. 2007).

At the Gamis farm, a sophisticated adaptive gazing management strategy has been employed for more than forty years to cope with the variability in forage. The basis of the strategy is a rotational grazing scheme: the pasture land is divided into 98 paddocks, each of which is grazed for a short period (about 14 days) until the palatable biomass on that paddock is used up completely, and then is rested for a minimum of two months. While such a rotational grazing scheme is fairly standard throughout semi-arid regions, the farmer on the Gamis farm has introduced an additional resting: in years with sufficient precipitation. One third of the paddocks are given a rest during the growth period (September–May). In years with insufficient rainfall this rest period is reduced or completely omitted. Once a year, at the end of the rainy season (April), the farmer determines – based on actual rainfall and available forage – how many paddocks will be rested and, thus, how many lambs can be reared. This strategy is a particular example of what has been called ‘rotational resting’.

Our field work in Namibia has shown that, on the one side, the Gamis farm is a typical example of rangeland use in Namibia: (i) the institutional form as a commercial (as opposed to: communal) livestock farm is the dominant one in Namibia; (ii) most of the commercial farmers employ a rotational grazing scheme.

On the other side, the Gamis strategy is also a special case as it represents a ‘good-practice’ strategy. The farming management system has been employed in a similar form for several decades and has proven to be successful in economic and ecological terms, as the farmer derives a viable livelihood from his farming activity and the farm's vegetation is in good shape. Also, during a prolonged drought during the 1990s, many neighbouring farmers had to give up their farms, while the Gamis farm continued to be viable. Finally, the Gamis farmer himself, and other Namibian farmers we interviewed, considered the Gamis farm to be a good example for a sustainable rangeland management in both economic and ecological terms.

6.2 Concepts: stocks, risk, and viability

Our research aim to derive basic principles for sustainable grazing management in semi-arid areas required analyzing the ecological-economic dynamics of the rangeland system. The dynamics of both ecological and economic systems are determined by durable structures (here: e.g. rainfall, vegetation, livestock, capital) and their interactions. In both ecology and economics the concept of *stocks* is used to describe such durable structures. Based on a set-theoretic approach, Faber et al. (2005) developed a unified ecological-economic concept of stocks describing entities considered as persistent over a certain period of time larger than the time scale of consideration in the study.

Stochastic fluctuations in rainfall are characteristic in semi-arid regions, causing stochastic fluctuations in both vegetation and livestock and, finally, in the income gained from farming. Hence, *risk* is a central concept in the analysis of semi-arid rangelands. How the exogenous risk of rainfall translates into income risk depends on the grazing management applied by the farmer as well as on socio-economic institutions of risk-management. To describe this type of risk, we employed and further developed the concept of *endogenous risk* (Baumgärtner 2006, 2007, Quaas and Baumgärtner, in press).

To assess the sustainability of management strategies under conditions of risk, we developed an ecological-economic notion of *viability* (Baumgärtner and Quaas 2007). Viability, in this sense, means that the different components and functions of a dynamic, stochastic system at any time remain in a domain where the future existence of these components and functions is guaranteed with sufficiently high probability. Hence, viability is an operational measure of strong sustainability under conditions of risk.

6.3 Generic ecological-economic models and specific results

At the core of the CML-approach are generic models that are developed with the aim to provide insights, both general and specific (cf. Section 5.2), into the sustainable management of semi-arid rangelands. Accordingly, in this section the generic models and the insights they provide will be presented jointly.

Generic models, as used in the CML-approach, bridge the gap between case studies and concepts. The case study of the Gamis farm, combined with ecological and economic knowledge, has shown that the permanency of the grass vegetation in spite of the fluctuations of rainfall and stocking with livestock is one characteristic feature of the ecological system. Thus, describing the grass vegetation by employing the ecological-economic notion of a stock is a central element of the analysis and of the modeling process. According to the approach of generic modeling, we described the state of the vegetation by the stock of reserve biomass on the pasture rather than describing each plant individually. Also, a characteristic property of the good-practice case study is the 'rotational resting' strategy employed at the Gamis farm. This led to the idea of assessing the relevance of 'resting' for the sustainability of the grazing management and under which circumstances a farmer will or will not choose a strategy with resting.

From both sides, ecology and economics, we started off with state-of-the art models. A sophisticated stochastic ecological model was available that described the ecological dynamics of the Gamis farm in a detailed way, including five soil/landscape types and four vegetation types (Stephan et al. 1998). Müller et al. (2007) used this model as the starting point to build a generic model of the ecological dynamics of the semi-arid rangeland. The resulting model abstracts from different soil types and considers one representative species of perennial grass. It incorporates the fluctuating rainfall, the vegetation, the livestock and their interaction as well as the grazing management in a very stylized way. The analysis of this model has shown that the relevance of rest periods depends on the environmental conditions. Under the conditions typical for semi-arid rangelands – variable rainfall and low growth rates of vegetation – rest periods are essential for ecological-economic sustainability as they reduce the variability of biomass and, hence, income from livestock farming, and, in the long-run, also for a high mean biomass and income (Müller et al 2007). Hence, resting was found to be a buffer mechanism.

From the economic side we started with a model of intertemporal decision making under risk (Gollier 2001), which connects the decision maker's aversion against intertemporal variability in income and risk aversion. As our central aim was to gain insights into the interrelation between risk management and uncertainty, we focused this model on the risk-aversion aspect by considering a myopic decision maker (Quaas et al. 2007).

In a fully integrated model (Quaas et al. 2007), we analyzed the farmer's choice of a grazing strategy and the consequences for sustainability depending on the farmer's risk aversion. We assessed the sustainability of grazing management by employing the concept of ecological-economic viability (Quaas et al. 2007, Quaas and Baumgärtner 2007).

It turned out that a farmer who is long-term planning or sufficiently risk averse chooses a sustainable strategy with resting (Quaas et al. 2007). If he is short-term planning and risk neutral, however, an unsustainable strategy without resting is chosen. This demonstrates that risk-aversion and the choice of an adaptive grazing strategy with rotational resting are instrumental for the sustainability of semi-arid rangelands. As a general insight, this shows that short-term optimization does not automatically exclude sustainability, but that, under certain conditions, a sufficiently high degree of risk aversion implies sustainability (Quaas et al. 2007).

In order to further explore the implications of this result, we included the relevant institutional context in a generic way by considering the possibility of financial insurance against income risk. We found that the introduction of an idealized income insurance (Baumgärtner 2007, Quaas/Baumgärtner in press) or a rain-index insurance (Müller et al. 2008) can lead to an unsustainable outcome, depending on the ecological setting at hand and on the exact type of the insurance scheme. Deriving conditions about how to design insurance contracts (Müller et al. 2008), these results can be fed back into the actual processes of decision making in Namibia, for example by advising banks, insurance companies, or agricultural co-operatives.

6.4 Value added by the CML-approach

The CML-approach provided the basis for a fully integrated interdisciplinary analysis of the sustainability of grazing management strategies and was essential to derive the results presented in the previous section. In particular, the simultaneous analysis at all three levels of abstraction – case studies, models and concepts – was necessary:

- From the case study of the Gamis farm, we derived hypotheses about what are the crucial elements of a sustainable grazing management strategy in semi-arid regions. For example, on the basis of the case-study we hypothesized that rotational resting is critical for the sustainability of livestock-grazing in semi-arid regions (Müller et al. 2007).
- The analysis of this hypothesis was only possible through the use of generic, fully integrated ecological-economic models because feedbacks between the ecological dynamics and the economics of decision making are crucial for livestock grazing in semi-arid regions. For example, the extent of resting has been found to determine the future state of the vegetation and, at the same time, current income. In particular, it determines the risk-characteristics of current income. The result that short-term optimization does not automatically exclude sustainability, but rather that risk aversion can already imply sustainability, hinges upon this ecological-economic feedback mechanism (Quaas et al. 2007).
- In order to build and to analyze fully integrated, generic models it was necessary to develop unified ecological-economic concepts. For example, the unified ecological-economic notions of stocks, endogenous risk, and viability were necessary to describe the ecological-economic dynamics and risk management in a unified way, and to assess in ecological and economic terms the sustainability of livestock-grazing under conditions of uncertainty (Quaas et al. 2007, Baumgärtner and Quaas 2007).

The line of argument linking the sustainability analyses across the different levels of operationalization is provided by a cascade of research questions subsequently generated in the course of the study (resting as observed characteristic of an implemented grazing strategy -> ecological buffer mechanism -> interplay between ecological and economic buffers -> conclusions on the design of income insurance schemes). The CML-approach with its modular multi-level architecture facilitates such a hierarchical way of generating knowledge.

The rotational resting strategy implemented at the Gamis farm can be interpreted as an example of ‘practical knowledge’. The CML-approach reveals that this ‘practical knowledge’ is not a substitute for the ‘scientific knowledge’ attained through systematic sustainability analyses of any implemented management strategy by the mean of modeling. This is especially relevant in face of the ongoing global change. These change processes can critically alter the interactions in and, hence, the entire dynamics of ecological-economic systems. As a result, management strategies that would be sustainable under current conditions can become inadequate. The adequateness of a certain strategy under modified conditions can only be assessed in a scientific analysis. The CML-approach provides an appropriate framework for such tasks.

7 Conclusions and Perspectives

We have developed a consistent and comprehensive multi-level approach to ecological economics (*CML-approach)* which integrates philosophical considerations on the foundations of ecological economics with an adequate operationalization. Taking the subject matter and aims of ecological economics as a starting point, we have identified a specific understanding of inter- and transdisciplinarity, and the underlying epistemological position on which this approach is based. In accordance with this understanding of inter- and transdisciplinarity and the underlying epistemological position, we have suggested an operationalization which comprises simultaneous analysis on three levels of abstraction: concepts, models and case studies.

The innovation of this approach is that it represents a systematic and coherent methodological framework for ecological economics, ranging all the way from basic philosophy of science to concrete operationalization. It offers a systematic view on EE, and thus allows one to see the relationship between contributions to that field that have so far been perceived as very heterogeneous and largely unrelated. This includes a vast diversity of contributions which are (i) based on case studies, models, theories, conceptual foundation, philosophical reflection; (ii) aim at positive analysis in the spirit of the natural sciences (i.e. describing facts and providing explanations), or at normative, i.e. value based, policy recommendations, or at both; (iii) are motivated purely by cognitive interest and are driven by a science-immanent logic (i.e. study questions from science and provide answers for science), or by an interest in practical action and solution (i.e. link science and society), or by some combination of both.

There are three main conclusions from our analysis. First, our analysis gives firm philosophical support to the widely held position of *methodological pluralism* in ecological economics (Norgaard 1989), and at the same time restricts its misinterpretation as unconditional, and therefore arbitrary, openness to just everything. The rationale behind the plurality of methods in, and approaches to, ecological economics is the underlying plurality of fundamental philosophical positions – such as rationalism and empiricism, motivation by cognitive interest or action interest, or value-freeness and value-integration – which are all legitimate and potentially valuable with respect to the subject matter and aims of EE. So, the apparent heterogeneity of approaches, methods and contributions is not per se problematic but rather necessary to EE. The CML-approach provides a methodological framework to systematically structure and to relate this heterogeneity on a meta-level, in a way which is directed towards the subject matter and aims of EE. Such a unified perspective on a meta-level, on the other hand, establishes certain requirements on the plurality of methods and approaches, going beyond "pluralism" in the sense of unconditional and arbitrary openness. Methodological pluralism per se will not necessarily foster EE, but requires a unified basis. It needs to be consistent with, and systematically directed towards, the subject matter and aims of EE. The CML-approach can help identify these requirements.

Second, our analysis has implications about how to do ecological economics in a fruitful and potentially successful manner. We believe that the CML-approach can serve as *guidance* not only for the field of EE at large, but also for every individual contribution to EE. For example, simultaneous analysis on the three levels of concepts, models and case studies should, at least potentially, be part of every contribution to EE. While the focus of an individual contribution may, of course, be on one particular level of analysis, the context of the other levels and the entire spectrum of levels need to be present at least potentially. This provides a meta-methodological *criterion* of how to do EE, which could be used as one essential criterion (among others) to evaluate and assess contributions to EE. In particular, philosophical reflection on the conceptual level as well as thinking in empirical contexts is constitutive and indispensable for all work in EE.

Third, our analysis reveals that EE requires specific *personal and professional capabilities* of ecological economists in addition to the more general scientific skills and capabilities that are required for every scientist (see also Faber 2007). This has implications, for example, for the education of ecological economists. (i) Interdisciplinarity requires that an ecological economist has a basic understanding of the differences among scientific disciplines and the specific character of each discipline. This does not mean that each ecological economist has to be capable of making a scientific contribution to every discipline in an interdisciplinary endeavor. Yet, each ecological economist should have a basic understanding of every discipline relevant to their specific research topic in terms of its self-understanding, methodology, concepts, models, etc. (ii) Each ecological economist needs basic philosophical knowledge about norms, knowledge, science and their roles in society (i.e. epistemology, ethics, philosophy and history of science). This includes a distinction between different forms of knowledge (i.e. scientific and tacit knowledge) and the distinction between factual and normative knowledge. (iii) For ecological economists, communication skills are critical. In the inter- and transdisciplinary discourse, notions of one particular scientific discipline have to be communicated from the perspective of that discipline to other disciplines or society at large. Together with other disciplines or societal stakeholders they have to be developed into inter- and transdisciplinary notions that fit with the overall inter- or transdisciplinary aim. This requires an awareness of the differing use and potential connotations of notions in different disciplinary and societal discourses, in particular of those notions that are apparently the same in different disciplines.

As we have argued for reflexive and guided pluralism in EE, we explicitly do *not* draw the conclusion that the CML-approach is the only or “the best” approach to EE. Yet, we believe that the approach has potential (and, of course, limits) as both a description of, and a guide to, ecological economics.

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