ECONSTOR
Make Your Publications Visible.

A Service of

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Köhn, Jörg

Working Paper

Thinking in Terms of System Hierarchies and Velocites. What makes Development Sustainable?

Thünen-Series of Applied Economic Theory - Working Paper, No. 04

Provided in Cooperation with:
University of Rostock, Institute of Economics

Suggested Citation: Köhn, Jörg (1996) : Thinking in Terms of System Hierarchies and Velocites. What makes Development Sustainable?, Thünen-Series of Applied Economic Theory - Working Paper, No. 04, Universität Rostock, Institut für Volkswirtschaftslehre, Rostock

This Version is available at:
https://hdl.handle.net/10419/78267

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

WWW.ECONSTOR.EU

Mitglied der Leibniz-Gemeinschaft

Thünen-Series of Applied Economic Theory

Thünen-Reihe Angewandter Volkswirtschaftstheorie

Working Paper No. 4

Thinking in Terms of System Hierarchies and Velocities.

What makes a Development Sustainable?

von

Jörg Köhn

Universität Rostock

Universität Rostock
Wirtschafts- und Sozialwissenschaftliche Fakultät
Institut für Volkswirtschaftslehre
1996

Thinking in Terms of System Hierarchies and Velocites.

What makes Development Sustainable?

Jörg Köhn[1]

Abstract

In order to understand the context for sustainable development policies it is necessary to understand how different rates of evolution and velocities of change within social and ecological systems affect interactions between and the co-evolution of those systems. Sustainable development policies will bear fruit only when we can discuss sustainable development not only of separate interdependent or nested systems in a global hierarchy, but also in relation to their widely varying, but interrelated rates and courses of development and evolution.

1 Introduction

Politics, economics and science the sustainable development concept in various ways. No universally accepted definition exists, nor have reliable indicators been identified. This is surprising as the concept was first mentioned in the writings of MILL (1848) and MALTHUS (1836, cf. GOODLAND 1995). As early as 1849 FAUSTMANN used a similar concept to calculate the forest rotation period to maximize returns (LUDWIG 1993).

The concept has also attracted more recent attention with more diverse interests in mind. Following up earlier attempts, economists developed the Maximum Sustainable Yield concept (MSY, cf. PEARCE and TURNER 1990) for managing renewable resources. However, their approach is strongly reductive in its treatment of environmental

---

[1] University of Rostock. The paper is based on a manuscript „Models for Sustainable Policy“ presented at the Brown University, R.I., the Rensselear Polytechnic Institute, Troy, N.Y., and the University of Wisconsin, Madison. The later paper has been split into four parts. The other three will be published under the titles „Hierarchy and velocity of systems. What makes a development sustainable?“, „Institutional economics, multi-species resource uses and sustainability“, and „Sustainability, carrying capacity and resilience in a systems hierarchic approach“.

variability. Moreover, it can only be applied to a one resource-as-commodity approach. Hence, the definition reflects only one component of the sustainability concept, that of „carrying capacity“ and the „non-overexploitation“ rule. Though these ideas are certainly needed to define sustainable development, they do not themselves explain what makes a system sustainable (GOODLAND 1995, p.11).

GOODLAND (1995, p.2ff) distinguishes economic sustainability from its more comprehensive social and environmental counterparts. He recognizes the varying degrees with which sustainability can be understood and implemented, describing the various target states as weak, strong and absurdly strong sustainability. In this classification, economic sustainability tends to be associated with weak sustainability, while social and environmental sustainability are considered stronger concepts.

In a political sense, however, social and environmental sustainability can not be considered separately from economic sustainability. Sustainable development policy must focus on providing a framework for broader social and environmental decisions rather than on capital substitution alone. In its political context, sustainable development becomes a set of political actions aimed at „development that meets the needs of the present without compromising the ability of future generations to meet their own needs“ (cf. THE BRUNDTLAND COMMISSION 1987). This necessarily implies other targets than simply maintening the overall capital stock. It implies that social (intra- and intergenerational) and environmental equity, ethics, social institutions, conservation of cultural diversity and biodiversity are all components of the concept of sustainability.

Our paper begins with concepts for sustaining the resource base for the economic system by appropriate institutions and takes this as its basis to discuss the sustainability of economic systems. The second section deals with the contributions of BOULDING (1966, 1969), GEORGESCU-ROEGEN (1971, 1975) and DALY (1973, 1977, 1987, 1990, 1992), focusing on the thermodynamic and socioethical aspects of sustainable development, i.e. on the relations between material, energy and *information* vectors in system evolution. Almost all literature on sustainable development has focused mainly

on material and energy approaches. This paper, therefore, broadens the discussion by focusing on *information* and its partial codification in institutions. In other words, it integrates DAWKIN´s concept of *information* replicators (genes and memes) needed to analyze and explain evolutionary and co-evolutionary processes. Taken together, these concepts allow us to compare and rank systems in hierarchies. Moreover, they permit velocities of change in nested systems to be compared and conclusions to be drawn about feedback mechanisms in such systems.

It should be noted that the development of appropriate mathematical models is hindered by the complexity and nonlinear adaptational and evolutionary processes in the systems and the inherent uncertainties they introduce (cf. COSTANZA et al. 1993, p.546). Therefore the paper adopts a primarily - though not entirely - literary description rather than a mathematical approach to draw its conclusions on feedback mechanisms, the driving forces for adaptation and evolution, and the stabilizing mechanisms within systems. Finally, due to the inherent and lasting uncertainties of systems, the paper utilizes aspects of institutional economics.

2. Sustaining the resource base for the economic system

Neoclassical economics supplies models allowing intertemporal (physical and economic) scarcities (of resources) to be considered. Physical scarcity is a consequence of the need to distribute a finite resource, e.g., among a growing population (the problem of allocation and re-allocation). The „capacity of the earth“ describes in model form a calculated „optimum population size“ and the corresponding „per capita amount of resources available for consumption“. It assumes that, in an ideal world, exhaustible resources can and will be replaced by renewable or recyclable substances. They also assume that price signals will modulate the behaviour of the players (demand) in the event of economic scarcity: economic subjects will decide rationally in response to price signals, and demand for a scarce resource will therefore decrease as prices rise. Since this will reduce consumption of the residual stock, the resource will be conserved.

Besides rational decisions, this model presupposes that the economic subjects possess (complete) knowledge concerning the resources endogenized in a product and its

substitute (with the same or enhanced properties in the form of a comparable product) and also concerning their own preferences. In addition, the subjects must also be able to maximize the calculated use to themselves within this framework - related here to a product. In other words, such models do not allow incomplete *information*. They are abstractions from real world phenomena (cf. DALY 1992, p.185). This is particularly evident when considering the sustainable management of a single-resource-commodity as a concept for global application: levels of knowledge would have to be the same all over the world. Apart from that, however, uncertainties also arise from questions for which we have no answer:

How large is the stock of each exhaustible resource?
How much environment/of a resource does a person need?
How many people can the earth support?

To these uncertainties and the corresponding transaction and *information* costs resulting from incomplete *information* must be added the general uncertainties caused by the factor time in relation to economic activities (variations in interest rates, levels of knowledge, etc.). These uncertainties are unavoidable and system inherent (e.g. non-linear causal chains, singularities in chaotic systems). In human societies this problem is usually solved or ameliorated by creating suitable institutional structures or institutions (e.g. NORTH 1988).

Institutions have already been set up to handle some of the uncertainties associated with resource use -- such as international treaties regulating the exploitation of various fish stocks under the supervision of the International Council For Exploration of The Seas (ICES). Treaties such as these regulate national quotas in a quasi-monopolistic market, but are still unable to take uncertainties stemming from environmental and social perturbations or simply moral risk behaviour into account in their resource management models.

Elinor OSTROM (1993, p.8,9) shows that other institutions may be very effective in regulating local resource scarcities by cooperation.[2] These „... simple, small, and isolated natural resource systems are characterized by:

- a small and stable set of users able to communicate on a face to face basis,
- predictable and easily measured flows of benefits and costs, and
- symmetry of *information*, asset structures, capabilities, and preferences."

It is scarcely conceivable, however, that the local, lowly social and environmental sustaining systems which OSTROM described can be scaled up to provide rules for larger systems such as world stocks involving heterogeneous players, multi-species or multi-product resources and longer time scales.

When designing institutions to regulate multi-species resource use and defining flexible frameworks for action, the system structures and functions must be faithfully reflected in and incoporated into those institutions. Institutions established to achieve sustainable resource use must therefore take into account system-inherent uncertainties, i.e. factors that exist outside the economic system but may at least influence the players in their decisions and actions (for instance religion, ethics, cultural beliefs, communication) in addition to those that vary in time besides allowing multiparameter control. However, institution themselves change in time in response to their changing environment, the interests of the players involved, etc. In other words, institutions themselves are, subject to adaptation, co-evolution and evolution (NORTH 1988).

3. Economic Sustainability

The lack of a strong definition for sustainable development has led to a dispute marked by widely differing standpoints in economic science - usually dictated by different goals - based either on concepts such as intergenerational and global justice, the integration of economy and ecology into economic development and growth concepts and the multiple use of resources (the ecological economics approach, e.g. BOULDING 1966, 1969;

---

[2] OSTROM (1990) describes the use of „common property resources" (CPRs) like mountain meadows and

GEORGESCU-ROEGEN 1971,1973; DALY 1973, 1977, 1987, 1990, 1992) or on the premise that the present generation is entitled to consume more resources than future ones because coming generations will be better equipped owing to their greater knowledge. Neoclassical economics assumes that endogenized progress in science and technology will provide adequate potential for the substitution of resources; therefore, their availability to future generations is irrelevant (the neoclassical approach). The latter approach assumes that natural capital will be replaced by complete substitution with human-made capital: „the world can, in effect, get along without natural resources" (SOLOW 1974) and relates mainly to the discussion of Solow-sustainability (comment by COMMON and PERRINGS, 1992, p.5) based on the Hartwich rule, where:

„Economic capital should be stable... The rule states that consumption may be held constant in the face of exhaustible resources only if the rents deriving from the intertemporally efficient use of those resources are reinvested in reproducible capital... The optimal policy for each generation is to maintain the existing capital stock. Investment should be equal to depreciation. ...each component of that stock is perfectly substitutable for all other components..."

However, this kind of „economic sustainability" ignores the distinction between endogeneous (system inherent) and exogeneous (external, but inherent in higher level systems) variables and processes forced and regulated by system adaptation and evolution. It also fails to take into account the way these factors are linked by self-regulation mechanisms and (the most important system property) their constantly changing structural and functional properties in time, their ability to adapt gradually to a changing natural and socio-economic environment and/or the opportunity to flip (LOVELOCK 1995).

Consequently, some assumptions of neoclassical economics are „no longer true" (COMMON and PERRINGS 1992, p.5) and, therefore, the „substitutability theorem" (GOODLAND 1995, p.15) will not hold when considering sustainability. However, if substitution of capital consisting of components such as natural, human, human-made and social capital is „defined to be a time-varying vector of heterogeneous capital stocks

---

forests, and irrigation instiutions by local communities that are directly depending from the CPR.

including exhaustible resources ..“ economic sustainability based on a homogeneous capital stock becomes impossible (COMMON and PERRINGS 1992, p.5). What would be the result of considering the different categories of capital? First, one would have to reject the substitutability thesis proposed by SOLOW and others. This in turn would imply that at least „parts of the capital“ are complementary. Second, one would have to clarify how these parts are interrelated, and third, it would be necessary to show that the various capital stocks possess stock-flow relations, including feedbacks, that could make development sustainable.

Leaving the concept of economic sustainability, one may turn to the definition proposed by DALY (1988, after GOODLAND 1995, p.4). He uses the term carrying capacity to define sustainability as :

„development without throughput growth beyond environmental carrying capacity ... which is socially sustainable.“

DALY´s interpretations and his model of steady-state economics are based on the findings of BOULDING (1966, 1969) and GEORGESCU-ROEGEN (1971, 1973), who both draw general conclusions about system properties that are crucial to the topic (next).

4. Towards sustainability concepts based on thinking in terms of system hierarchíes

4.1 Kenneth BOULDING´s contributions to the topic

Interrelations between social systems may be described as functions of the rate of exchange of material, energy and *information* between systems. This leads to a stock-flow-relation approach that can explain system development in terms of „birth“, „self-generation“ and „aging“ in both natural and social systems (BOULDING 1966, p.4,5). In this case, the exchange of material, energy and *information* is crucial for the survival of living systems. Measuring the inherent stock of material, energy and *information* in a system and the rates at which they are exchanged to identify the input-throughput-output relations permits assessment of the stability and velocity or processes taking place within the system and the detection of any deviations from a state of equilibrium.

„Acceleration“ of the rate at which a stock is exchanged would the rate of growth (BOULDING 1966, p.8) or, under certain circumstances, a deviation from the system´s state of equilibrium. The crucial points of BOULDING´s work on system sustainability are as follows.

Sustainable development occurs in an open system process.[3] System inherent processes sustain the system itself at least within certain limits.[4] Matter, energy and *information* are the crucial structural classes[5] of systems. Whereas matter and energy only enter the social/economic system insofar as they become an object of human interest, the self-generation of *information*[6] and its codified forms constitute „culture“ as a „set of common values“[7] defining specific social systems. The values defining a particular social system are subject to „mutation and selection“. BOULDING distinguished three types of „social organizers“ that differ in their institutional arrangements:

- the threat system (policy)
- the exchange system (economy)
- the integrative system (culture).

---

[3] „The open system, indeed, has some similarities to the open system of von BERTALANFFY, in that it implies that some kind of a structure is maintained in the midst of a throughput from inputs to outputs. In a closed system, the outputs of all parts of the system are linked to the inputs of other parts. There are no inputs from outside and no outputs to the outside; indeed, there is no outside at all. Closed systems, in fact, are very rare in human experience, in fact almost by definition unknowable, for if there are genuinely closed systems around us, we have no way of getting *information* into them or out of them; ...All living organisms, including man himself, are open systems.“ (1966, p.4)

[4] „...society ... we have an interesting example of system which seems to maintain itself by the self-generation of inputs...“ (p.5) , „...hen we are trying to obtain knowledge about a system by changing its inputs and outputs, these inputs and outputs will change the system itself...“ (1969, p.3)

[5] „Systems may be open or closed to a number of classes of inputs and outputs. Three important classes are matter, energy and *information*.“ (1966, p.5)

[6] „*information* is more subtle and harder to trace, but also represents an open system, related to, but not wholly dependent on, the transformations of matter and energy. By far the larger amount of *information* and knowledge is self-generated by the human society, though a certain amount of *information* comes into the sociosphere in the form of light from the universe outside. ...From the human point of view, knowledge or *information* is by far the most important of the three systems. Matter only acquires significance and only enters the sociosphere or the econosphere insofar as it becomes an object of human knowledge. We can think of capital, indeed, as frozen knowledge or knowledge imposed on the material world in the form of improbable arrangements...“ (1966, p.6)

[7] „...Every culture ... is defined by a set of common values ... and have been learned by the process by which all learning is done, that is, by mutation and selection.“ (1969, p.1), and „...three groups of social organizers ... the threat system, the exchange system, and the integrative system. Economics clearly occupies the middle of these three.“ (1969, p.4)

Since BOULDING (1969, p. 4) states that „these systems are linked together dynamically through the process of human learning which is the main dynamic factor in all social systems“ one may conclude that all three subsystems (policy, economy, culture) are components of a more comprehensive social system based on the replication and evolution of human knowledge (information). Thus, social subsystems are based on that part of the *information* pool which has been codified as institutions (rules, norms, rights). At the same time, these institutions will maintain social systems or parts of them by regulating, for instance, the use of matter and energy and creating new knowledge (e.g. technological progress) and further institutions.

4.2 Nicholas GEORGESCU-ROEGEN´s contributions to the topic

BOULDING uses thermodynamic principles in his considerations of the exchange of matter and energy in connection with system development. This approach to the economic discussion was pioneered by GEORGESCU-ROEGEN (1971). His findings show that if the economic system follows thermodynamic rules it must be nested in a higher ranked system: „nature“. Moreover, it exchanges at least matter and energy with this higher system and is therefore an open system. The system to which the economic system is open may be a source of negative feedbacks to the economic system. Entropy is inherent in living systems, causing co-evolution at and between their hiearchic levels. Additionally, entropy is a crucial indicator of system sustainability or non-sustainability. Moreover, if thermodynamic rules also govern social systems, social sustainability might not mean that the same level can be maintained eternally (cf. COSTANZA and PATTEN 1995, p.196). In other words, sustainable development is based on a dynamic concept of living systems that are subject natural laws. This in turn implies that the economic system is at least a subsystem of the natural system (FABER et al. 1987, p.13). The approach adopted by FABER and coworkers exceeds these system bounds and considers the economic system as a subsystem of the higher system „environment“. Fig. 1 is a simplified presentation of their approach. These authors also describe the polyvalent network of relationships and, like GEORGESCU-ROEGEN (1971, 1973), apply thermodynamic principles to the studied object. They also use a model to simulate the

interdependence of factors involved in economic activity (use of resources, application of capital, scientific and technological progress, see below).

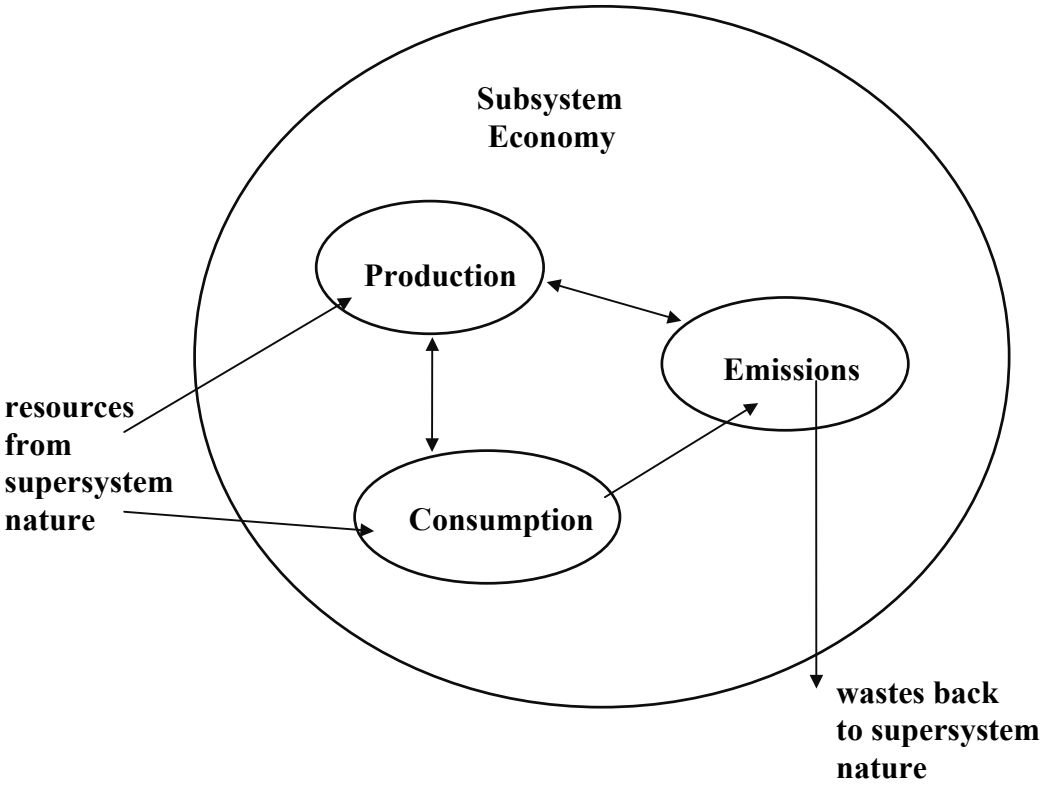

Fig. 1. The economic subsystem and its relations to the environment.

The exchange processes between a system's environment and economy consist in

a) the provision of resources for various economic activities,

b) the uptake of emissions produced by the economic process.

In this model, protecting the higher system, the environment, is an end in itself for the subsystem „economy“. Both the material and energetic aspects of the two-system case could be simulated if entropy could be quantified as a measure of degradation, and this would certainly yield consistent results. The interdependence of the two systems varies with the intensity of the exchange processes (transfer of matter and energy). Both systems are in a state of constant evolution, but the subsystem economy has to adapt to the evolution of the higher system environment. Spontaneous evolution of the higher system „environment“ is governed by, among other things, the laws of thermodynamics, and, as it is a subsystem, the economic system must also be subject to them (cf. GEORGESCU-ROEGEN 1971, p.57).

4.3 Herman DALY´s contributions to the topic

DALY (1973, 1977) introduced the concept of a steady-state economy as a „physical concept“ (1977, p.17) which can be interpreted as a concept for sustainable development. It is based on the assumption of „...physical populations - people and artifacts - existing as elements of a larger environmental system.“ (1977, p.15). Furthermore, „The economy ... is an open subsystem of a larger, but finite, ecosystem which is both the supplier of low entropy raw materials and the absorber of its high entropy wastes.“ (1987, p.324), and „Organisms cannot survive in a medium consisting of their own final outputs. Neither can economies. Like nature´s technology, man´s technology is strictly confined within the laws of thermodynamics.“ (1977, p.22, his fig. 3; p.35, cf. fig. 2). DALY then applies the concept of *scale* to economic systems. This is crucial for explaining interrelations in multihierarchical and complex systems, and for measuring the rate of change (velocities) in systems. He states:

„The growth of the economic subsystem is limited by the size of the overall system..., and by the intricate ecological connections which are more easily disrupted as the scale of the economic subsystem grows relatively to the total system.“ (1987, p.324)

The concept of scale is fundamental when dealing with complex and hierarchic systems (O´NEILL et al. 1989). Whereas, „the term *scale* ... refers to both the resolution (spatial grain size, time step, or degree of complication of the model) and extent (in time, space, and number of components modeled) of the analysis.“ (COSTANZA et al. 1993, p.548). The *scale* concept provides at least three methodological advantages. First, the dynamics and direction of the adaptation process (co-evolution in resilient systems) can be measured in terms of the intensity of matter and energy flows within and between systems. Second, it fits the input-output(-throughput) or stock-flow concepts used in natural science and economics. And third, it permits inclusion of interrelated conditions such as „finitude, entropy, and complex ... interdependence“ (1987, p.324), time and space vectors in the analysis of a system's adaptation and evolution. DALY´s steady-state concept reflects these biophysical constraints. DALY defined a steady-state economy 1977, p.17):

„*... as an economy with constant stocks of people and artifacts, maintained at some desired, sufficient levels by low rates of maintenance „throughput“,* that is, by the lowest feasible flows of matter and energy from the first stage of production (depletion of low-entropy materials from the environment) to the last stage of consumption (pollution of the environment with high-entropy wastes and exotic materials).“

These findings and interpretations are based mainly on the work of GEORGESCU-ROEGEN (DALY 1973, p.6). However, the steady-state concept also uses another approach, namely (1977, p.16):

„The culture, genetic inheritance, knowledge, goodness, ethical codes, and so forth embodied in human beings are not held constant. Likewise, the embodied technology, the design, and the product mix of the aggregate total stock of artifacts are not held constant. Nor is the current distribution of artifacts among the population taken as constant.“

DALY (1987, p.327) therefore introduces the a concept of „ethicosocial limits“. „Even while growth is still biophysically possible, other factors may limit its desirability ...“ and quoting HIRSCH (1976, in: DALY 1987, p.333) he goes on: „Economic growth undermines its (own) social foundations...“, and „...growth economy fosters the erosion of the values upon which it depends.“ (1987, p.335) Moreover, DALY continues, „...our inherent value systems are a product of random mutation and natural selection by the environment of the hunter-gatherer, and are not likely to be well adapted to the environment of atomic power and genetic engineering. ...Random mutation and natural selection by an evolving environment ...cannot possibly explain rational and moral thought itself...“. This implies:

„At a minimum the problem of sustainability requires maintaining intact the moral knowledge or ethical capital inherent from the past. In fact, sustainability really requires an increase in knowledge ... sufficient to offset insofar as possible, the inevitable degradation of our physical world.“ (1987, p.336)

This introduces an important point. Adaptation, system evolution and sustainability depend on feedback mechanisms anchored in culture (*information*). Socioethical limits seem to be feedback regulators.

DALY is not referring to BOULDING (1969, p.1) here although the findings of both authors are consistent with each other: What DALY calls „ethical capital and knowledge“ are „cultural values“ to BOULDING and „cultural capital“ to others (BERKES and FOLKE 1994). Moreover, like BOULDING, DALY uses the terms „mutation and selection“ to explain the evolution of „cultural values“ or „ethical capital“. In addition, DALY mentions that the „random mutation and natural selection“ of ethical capital is a slow process.

Since DALY uses BOULDING'S „classes“ matter and energy to explain biophysical limits, the „class“ *information* is appropriate for socioethical limits. DALY´s steady-state concept implies, moreover, the need to improve „ethical capital and knowledge“ as a crucial point within the sustainability concept. BOULDING posits that *information* is the class of the social system and, like „every culture“, is subject to evolution. If this is so, changes in the *information pool* reflect the evolutionary process of systems. Thus, *information* must be based on structural units which are subject to mutation and selection in a way similar to genes in the natural system (next chapter).

5. *Information*, replicators and its relation to „human capital“

Systems develop on the basis of their *information* stocks. HINTERBERGER (1992, 1994) uses the synonymous term „memes“ coined by DAWKINS (1989). FABER and PROOPS (1991, p.63) speak of a system's „potential“. BOULDING (1969, p.6) states that „the larger amount of *information* and knowledge is self-generated by human society ...“

Information is pooled. The *information pool* consists of a set of „frozen knowledge“ which human society generates by learning (BOULDING 1969, p.6) during the process of its own (genetic) evolution. The pool consists of various, for instance technological and traditional knowledge, social norms, rules and taboos or even knowledge about these components, etc. In other words, referring to economic capital theory, these parts of the *information pool* correspond to the various types of capital considered in economic theory, i.e. human capital, social capital, social overhead capital, cultural capital, etc.

The *information pool* is the structural frame for relations within a society, i.e. it is the potential (genotype) of a particular society sections thereof to express itself as a distinct phenotype. Conservation of traditional knowledge and creation of new knowledge, mutation and selection by learning are essential for human survival in different cultures (phenotypes). Whenever such system properties appear, questions arise as to the structural units that are suitable for mutation and selection.

In this respect, Richard DAWKINS (1976, citation follows the 1989 edition) draws analogies to genes as replicators of genetic *information*. In nature, *information* is pooled for each population, species and living component of natural systems in the genotype. The genome is the potential actually expressed in a given phenotype, thereby creating individuals, populations and the system itself. All components are subject to mutation and selection. In the short run, individuals adapt to the random conditions of the higher hierarchic level (adaptation): individuals in relation to the population they belong to, populations to other populations and the ecosystem they live in, the ecosystem to the geographic region and climate, and so on. These processes are modulated by feedback: each individual and population changes the structural and functional constraints of the system surrounding it. Conversely, the system will influence the selection process down to the population and individual levels (co-evolution). This later process is intertemporal. Changes taking place in the long term process include changes in the structure of the replicators (evolution). The long-term process therefore leads to structural and functional changes within the *information* pool (mutation) that vary in space and time and are scaled (see above). However, this description is not the whole truth. The *information* pool is also subject to erosion, for instance the extinction of species, and changes are not limited to gradual change in the long term perspective. Flips may happen, as demonstrated, for instance, by the five great extinctions that have occurred during the history of life on earth (LOVELOCK 1995). Moreover, the velocity of species evolution following such catastrophes is probably much higher then during „normal“ evolution. Naturally, care must be taken when drawing conclusions based on analogy to human *information* pools. The paper follows DAWKINS interpretations. He write (1989, p.189,192):

„Most of what is unusual about man can be summed up in one word: „culture“. ... Cultural transmission is analogous to genetic transmission in that, although basically conservative, it can rise in a form of evolution. ...“

This is reminiscent of BOULDING (1966, p.1), who considered culture as a set of common value set that evolves and is subject to selection. These values consist of, among other things, (DAWKINS 1989, p.190):

„Language ... fashions in dress and diet, ceremonies and customs, art and architecture, engineering and technology, ...“

These seem to be similar to needs, preferences, human capital definitions, etc. DAWKINS continues:

„...all evolve in historical time in a way that looks like highly speeded up genetic evolution, but have really nothing to do with genetic evolution. As in genetic evolution though, the change may be progressive ... it improves. Admittedly the current burst of improvement dates back only to the Renaissance, which was preceded by a dismal period of stagnation, in which European culture was frozen at the level achieved by Greeks. But as we saw ..., genetic evolution too may proceed as a series of brief spurts between stable plateaus.“

This gives rise to the question of resilience and equilibria (plateaus) during the development of human societies which are distinct in time and space scales (KÖHN in prep.). Surprisingly, human evolution does seem to exhibit thresholds indicative of punctuation. They are all linked to an increase in the rate at which knowledge is acquired and used to „improve“ conditions favouring survival. (The improvements were at least initially perceived as such). Typical thresholds in human evolution include, for instance, the replacement of the stone-age hunter-gatherer society during the agrarian revolution, the industrial revolution and, perhaps, the *information* revolution.

Learning from natural systems and their *„information processing“* raises questions concerning structures on which cultural/*informational* evolution is based. DAWKINS (1989, p.192) wrote in this respect:

„The new soup is the soup of human culture.“

His „soup“ consists of human needs, technical and social knowledge, knowledge about rules and norms, preferences, etc. (cf. OSTROM 1990). It is the superstructure, the metaphor to which all human *information* belongs. „Soup“ refers to the genome, to the pool of *information* that humans have created in their history and now possess. It is similar to BOULDING´s „frozen knowledge“, DALY´s „ethical capital“ or even the „human capital“ of economic theory. Moreover, this „genome“ is the „potential“ to create, manage and sustain social structures.

As in nature, this *information* will not be expressed in its entirety at any one time. The inherent regulators of a system, i.e. its „alleles“, consist of a reservoir of possible adaptations to a changing natural and social environment. Consequently, the extinction or nonexpression of an allele - which is the *information* needed to start, manage or end a certain process or even to synthesize a certain structure such as a protein - does not necessarily lead to extinction of the species or process possessing it. In general, depending on environmental conditions, it might even be possible that the allele is not lost, but merely replaced by another one better adapted to the new environment. But this is not a necessary condition. If the original allele survives in the genome of a species, it becomes recessive for its specific function. Although not used, it is still a constituent of the *informational* pool. This process, moving from one allele to another, could be simple adaptation. If the process is ongoing and the allele structure changes in the long term, the process tends to be co-evolutive. And, if the structure of the *information* encoded in the alleles changes, thereby modifying, say, the process of synthesizing a specific protein, the change is evolutive.

Like the gene pool in nature, the human *information* is not homogeneously distributed all over the world. DAWKINS (1989, p.191) drew attention to the

„...cultural evolution, and the immense differences between human cultures around the world...“

The part of the pool to be expressed depends on adaptational, co-evolutionary and evolutionary processes. The various expressions of the human *information* pool are the phenotypes found as different „cultures“ around the world. They exist separately and exhibit immense differences expressed, for example, in the form of language and

religion. And, they are copied within these different cultures by a process of „*imitation*“ (DAWKINS 1989, p.192). In a self-copying process knowledge is transmitted by „learning“ (BOULDING 1969, p.1) from generation to generation. Recently this process has also been seen to cross cultural boundaries.

DAWKINS (1989, p.192) names the „memory“-based finestructure of *information* the „*meme*“. The „soup of human culture“, therefore, consist of „*memes*“. These are the structural units of cultural transmission. They are subject to change in the course of adaptive, co-evolutive and evolutive processes. And they also link the subsystems of the human/social system as „the main dynamic factor in all social systems.“ (BOULDING 1969, p.1,4). Like genes, *memes* are distinct in certain properties (longevity, fecundity, copying-fidelity) (DAWKINS 1987, p.194). Moreover, *memes* originated in genetic structures:

„The old-gene selected evolution, by making brains, provided the soup in which the first memes arose. Once self-copying memes had arisen, their own, much faster, kind of evolution took off.“ (DAWKINS 1987, p.194). In the next chapter we shall consider what bearing this has on thinking in terms of system hierarchies, system structures, institutions in social systems, evolutive processes and their rates of change

6. New thinking in terms of system hierarchies

Models used in economics portray relations between the systems „environment“ and „economy“ in various ways. Whereas neoclassical economics considers and treats the environment problem as extrinsic (e.g. SIEBERT 1994), evolutionary economists regard the two as coexistent (e.g. BECKENBACH 1991, p.64; HINTERBERGER 1994, VAN DEN BERGH and NIJKAMP 1991).

This functional outline will now be applied to a more complex structure. More specifically, we shall attempt to identify the cause of the different rates of evolution. FABER and PROOPS (1991, p.75) described the rapid (unpredictable) formation of the „genotype“ of the physical system we now use as various physical constants to explain and calculate processes. They postulate a „unique genotype“ for physical systems and

increasing diversification for natural systems (corresponding in this case to at least the genetic potential of all species) and economic systems. The „genomes“ of economic systems determine such things as preference orders of the economic subjects, technology, the legal system and economic and social institutions. They are in fact stocks of *information* (the „genomes“ of human progress). On this basis, the economic „phenotype“ is the expression of a *memone*, to use DAWKINS term, under the given conditions (technologies in current use, capital consumption per unit good, quantities and prices of goods, market structures, etc. ibid., p.76).

The economic *memone* is not expressed globally. Knowledge erodes, and technologies are/have been forgotten. Local, regional and national adaptation to the global economic „genome“ founders on the transferability of knowledge between cultures, cultural-religious or other obstacles. In other words, genotype transfer (in the sense of our definition of the knowledge stock) was/is completely/partly blocked. Its phenotypic expression must consequently be based on „presence“ in a way analogous to how biological species adapt (using the species' potential in a biogeographical region) by partly absorbing and storing additional (and currently unused) *information*. The *information* stored in alleles for the synthesis of isoenzymes with different optimum temperatures is a good example of this. What in a biological context represents a stabilization of the species or system by permitting other genetic switches to be turned on in the face of change in the surrounding system would be, in an economic system, the encoding of knowledge acquired in adapting to surrounding systems and its activation when needed.

What can this surrounding system be? Does the two-system model possibly contain some decoupling mechanism leading to exacerbation of the conflict between the economic and the ecological system despite the existence of a „rational (?) economic genome“? If such a decoupling exists, how can we explain the measurable (for instance in terms of resource consumption) acceleration of the process since the industrial revolution in order, ultimately, to find approaches to a back-stop co-evolution?

Analysis of the economic system proposed by FABER et al. (1987, p.13) and the economic genome of FABER and PROOPS (1991, p.76) in the light of NORTH'S work (e.g. 1988) leads to a modification of the system-hierarchic view.

As a first step, the economic parts of the genome related to finance capital stock (preference orders of the economic subjects, technologies, economic institutions) can be separated out from the „economic genome". These form the genome of the economic system. Secondly, the institutions of the state and its legal system are regarded jointly as the „genome" of the political system (institutional non-transferable capital stock). Finally, history, belief, values outside of the consolidated preference orders are lumped together to form „cultural capital stock" and regarded as the „genome" of the cultural system. National and/or ethnic traditions are thus incorporated into the system model. The cultural system is regarded as decisive for the inertia of social systems. However, a clearcut separation between the subsystems seems to be impossible or even inappropriate to systems thinking.

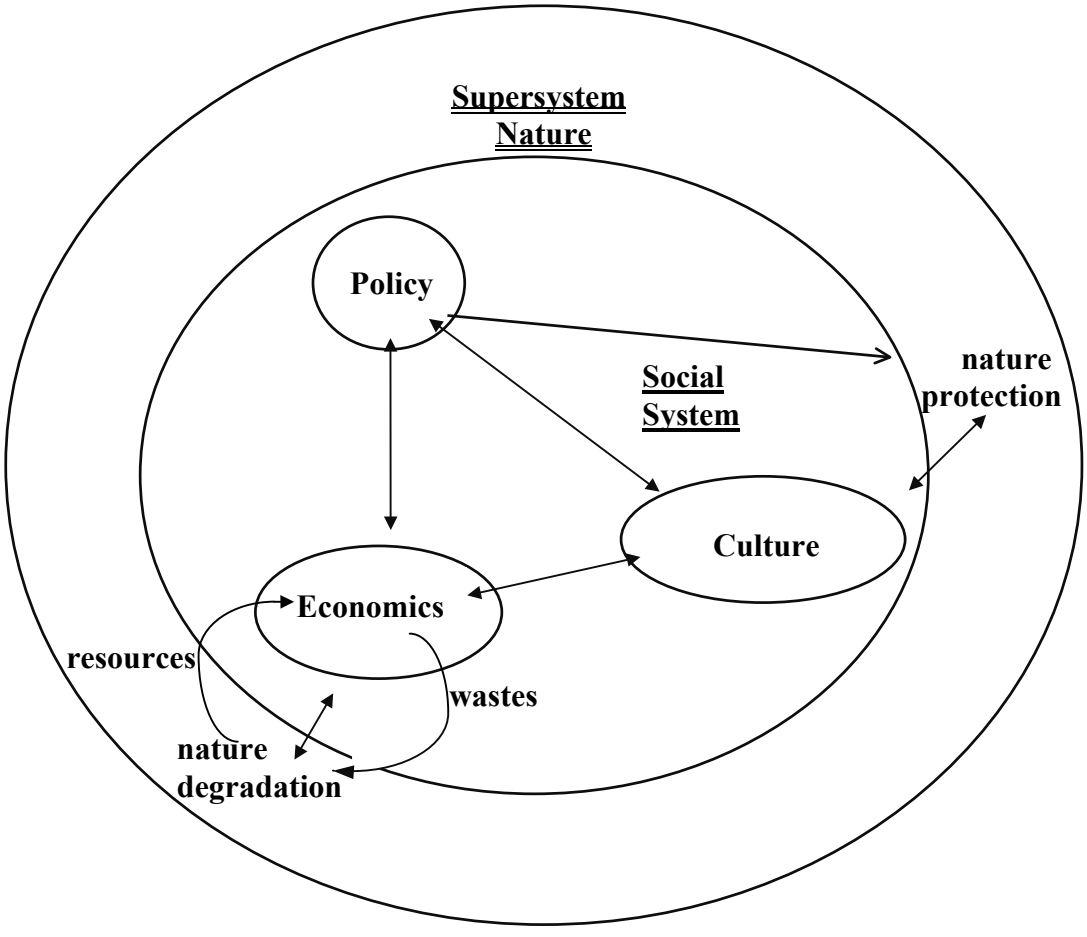

Fig. 2. The new system hierarchy concept.

The three newly formed systems are part of the social system (Fig. 2). They development partly independently of each other owing to the accumulation (and erosion) of the *information* stock (evolution of their distinct „capital stocks“). The subsystems are balanced by flows between capital stocks. These take the form of adaptation in which local, regional and national (as a sum, global) phenotypes are formed. Inputs of exogenic *information* can from time to time increase the diversity of the system, but also take it closer to its carrying capacity and can, under certain conditions, lead to the collapse of the system. At some stages, feedback must exist between the subsystems to control their rates of development, i.e. each subsystem must have time to adapt to the development of the others. Although trigger and carrier feedback mechanisms analogous to those of enzyme cycles could serve as regulating instruments, little is known about such mechanisms in social systems. Ever since the division of labour towards the end of primitive society, and certainly since the industrial revolution, evolutive and co-evolutive processes in the social system have been taking place at a substantially faster pace than in nature, the supersystem. As a result, the risk and unpredictability of paths of development and fixed points has also increased („unpredictable uncertainty“).

The social system gradually replaces the economic submodel in the considerations of FABER et al. (1987, p.13, Fig. 1). That is, an additional co-evolutionary process takes place between the social system and natural system within the supersystem nature (or ecological subsystems in a biogeographical region). This process is inevitably slower than processes between subsystems of the social system, but is strongly influenced by their rates.

Rates of evolution will differ from one level to another of the different processes (Fig. 3, Table 1), knowledge transfers and species even within the subsystems. They depend on the genetic „stability“ of the various attributes (endogenic stability) and on exogenic factors such as those exerted by systems higher up in the hierarchy. After all, attributes faced by minor „genetic barriers“ (e.g. viruses and bacteria with enormous

rates of reproduction and „naked“ genomes“, cf. COSTANZA and PATTEN, 1995, p.194), like partly open systems, tend to have higher rates of evolution than closed systems owing to their more intensive exchange processes with their surrounding systems.

In contrast to the models discussed at the beginning, the model considered here expands to form a three-level hierarchy with subsystems at each level (Fig. 3). The rates of subsystem evolution increase as the degree of concentration. Feedback takes the form of adaptation of the new phenotype to the hierarchically higher system or to the source reference system. Actually, BOULDING'S (1969, p. 2) „mutation selection process“ takes place at the level of the social systems and between hierarchic levels and is limited to the *information* vector. Attributes subject to evolution and co-evolution and the feedback and carrier mechanisms presumably correspond to the species, genes and alleles and their replicators found in biological systems.

Fig. 3a. The One-Level Hierarchy and possible relations between systems.

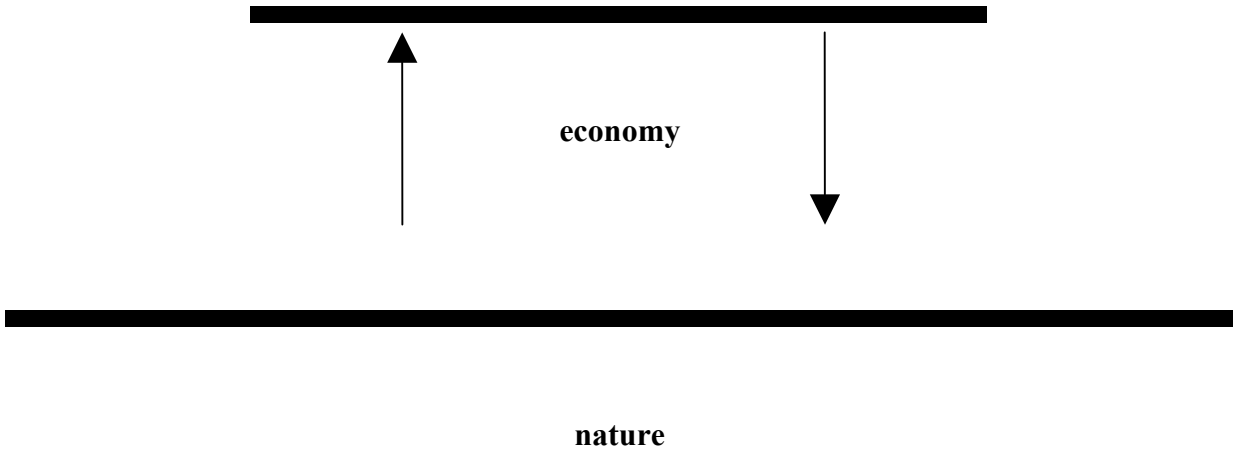

Fig. 3b. The Two-Level Hierarchy and possible relations between systems.

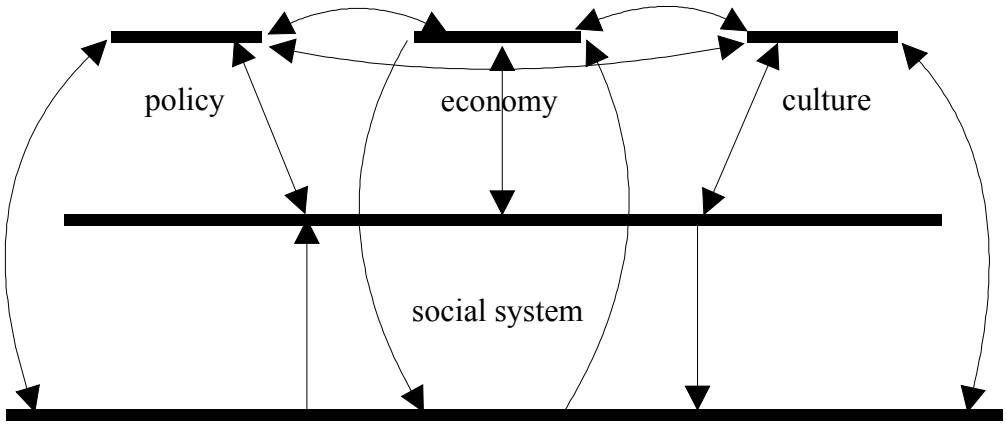

Fig. 3c. The Three-Level Hierarchy and possible relations between systems.

Tab. 1. Velocity of Adaptation and Sensitivity to Evolution of Sytems.

	velocity of adaptation	**sensitivity to evolution**
natural systems	slow	very low
social systems		
- cultural systems	slow	low
- political systems	medium	slow
- economic systems	fast	medium

7. System velocity

Table 1 summarizes our knowledge concerning rates of change in a simplified manner. Velocity of adaptation means a shift between alternatives (alleles), whereas sensitivity to evolution reflects more the co-evolutionary and evolutionary rate of change. However, the table only reflects the behaviour of systems during gradual processes. It does not take punctuated events (flips) into account. The table is based on quotations given in the

text and an estimation of rates of change in the new systems model. In general, the lower the position of the system in the hierarchy, the faster the rate of change. Acceleration occurs first of all in the economic system. This subsystem, however, is also the most open one in respect of fecundity and copying fidelity as a result of, for instance, internationalization processes in industry and the processing of technical *information*. Longevity of replicators is the opposite extreme. This implies that the economic subsystem itself leads to loss of cultural values and *information*. Here, moreover, we have an analogy to the law of entropy: the more *information* is produced, and the more frequently it is produced and copied, the more susceptible it and its copies will be to failures and losses. Since this is a new topic, I am not quite sure of the consequences. But, thinking in terms of systems leads, in analogy to the second law of thermodynamics, to the conclusion that the effect of *information* waste may be similar to entropy.

8. Validity of the model for sustainable policy concepts

The system bounds of the model we have described can be set at the local, regional, national, continental or global decision-making level. The determinants set by the supersystem „nature“ consist in climate, biogeographic features and the resource stock. The social system developed and is developing against this and a historical background. The evolution of the social system is the result of the development of the „genomes“ of its subsystems, the expression of specific (for instance national) phenotypes and the adaptation of the subsystems to each other and to hierarchically equal and higher systems (co-evolution). The degree of development of a system can be characterized by the expression of its *information* stock (potentials), but not necessarily by its complete, simultaneous expression. The *information* stock can both increase and erode.

Sustainable policies should therefore be oriented towards safeguarding and using the endogenic *information* stock (retention of the cultural capital stock, which is partly identical to human capital). Inputs (flows such as technical knowledge) must be measured in terms of their adaptability to the cultural and political system and should not lead to saltatory evolution. In other words, free transferability of, for instance,

technical knowledge, preference hierarchies or economic institutions can lead to an (unpredictable) risk for the social system and even for the supersystem nature (non-linear cause-response-functions).

However, BOULDING (1966, p. 5) states that three „classes of inputs and outputs“ must be taken into account, implying that sustainability policies will involve more than the bare necessities „matter“ and „energy“. The problem of sustainable development can be solved only by encouraging „synergetic feedbacks between human societies and their environment“ (BERKES and FOLKE 1994, p.134). Therefore, appropriate institutional settings (for sustainable policies) can be established and concepts supporting the sustainable use and conservation of resources („sustainable management“ in production, product and service development and availability, consumption, recycling and reintroduction to „natural“ material fluxes) developed only if the long term uncertainties can be reduced.

Uncertainties stem from lack of knowledge about system structures and functions and their variability time. Moreover, *information* is also needed about the players, possible alternative decisions, indicators, social and institutional arrangements, system inertia and the factors triggering development. In other words, sustainable development is only possible if evolutive and co-evolutive processes are known and partly directable. Therefore, at least something must be known concerning the regulability and controllability of the systems involved.

As a rule the larger and more complex a system, the larger the uncertainties concerning the system itself and its relations to other systems. Small systems with a limited number of players, rules and decisions tend to more sustainably developable than complex and unfathomable systems (OSTROM 1993, HOLLING et al. 1993, BERKES and FOLKE 1994). Thus, the more complex the system, the greater the need for appropriate institutions. These institutions will reduce uncertainties and lower transaction costs (NORTH 1988). Furthermore, they will stabilize social systems by conserving cultural values and cultural diversity. However, „large systems ... involve substantial difficulties. These are associated with large and heterogeneous numbers of individual and corporate actors and with difficulties in making credible commitments. ... Consequently, in future

work, it will be important to pursue theoretical and empirical studies that specifically address how heterogeneity of participants, multi-species or multiproduct resource systems, and long time horizons affect the selection and performance of institutions.“ (OSTROM 1993, p.9) Although Elinor OSTROM´s research focuses on the use of resources and not on systems, many parallels can be seen. Institutions for governing the commons bear close similarities to institutions for sustaining systems. Institutions are among the „cultural values“, „written“ in memic codes. They set frameworks for action and support links between material-energy-*information* classes.

The new systems hierarchy concept can be used to explain the different rates/velocities of adaptation, co-evolution and evolution: *information* and the institutions based on it appear to be the crucial components of the sustainability concept. This implies that material-energy approaches are inadequate for the sustainability game. Moreover, the sustainability discussion must be broadened to embrace new approaches in the economic theory of uncertainties, *information*, institutions and game theory rather than restricting itself to simplified material-energy or capital-maintaining approaches.

Acknowledgements

The author expresses his gratitude to Faye Duchin, Richard Bishop, Daniel Bromley, John Gowdy, Talbot Page, Danilo Pelletiere, Wilfried Siebe, the participants of the session „Sustainability I“ at the Ecological SummerSummit, Copenhagen, August 19, 1996, and the participants of the expert seminar „Managing Sustainability from the Ground Up“, Vilm, August 24 - 28, 1996, for helpful discussions.

Thanks are also due to Brian Patchett (Intertext Rostock) for editing the English text.

References

BECKENBACH, F., 1991. Zwichen Frosch- und Vogelperspektive: Das Ökologieproblem als Verknüpfung von ökonomischer Entscheidungs- und Reproduktionstheorie. In: BECKENBACH, F. (Ed.): Die ökologische Herausforderung für die ökonomische Theorie, Metropolis Marburg, pp. 63-108.

BERKES, F. and FOLKE, C., 1994. Investing in cultural capital for sustainable use of natural capital. Beijer Reprint Series, 22, pp. 128-149.

BERKES, F. and FOLKE, C., 1994. Linking social and ecological systems for resilience and sustainability. Beijer Discussion Paper Series, 52, pp. 1-16.

BOULDING, K.E., 1966. The economics of the coming spaceship earth. In: JARRETT, H. (Ed.).: Enviromental quality in a growing economy. John Hopkins Press, Baltimore, pp. 3-14.

BOULDING, K.E., 1969. Economics as a moral science. American Economic Review, pp. 1-12.

COMMON, M. and PERRINGS, C., 1992. Towards an ecological economics of sustainability. Beijer Discussion Paper Series, 2, pp. 1-30.

COSTANZA, R., WAINGER, L., FOLKE, C. and MÄLER, K.-G., 1993. Modeling complex ecological economic systems. BioScience, 43, 8, pp. 545-555.

COSTANZA, R. and PATTEN, B.C., 1995. Defining and predicting sustainability. Ecological Economics, 15, pp. 193-196.

DALY, H.E., 1973. Introduction to the steady-state economy. In: DALY, H.E. (Editor), Toward a steady-state economy. W.H. Freeman and Company, San Francisco, pp. 1-32.

DALY, H.E., 1977. Steady-state Economics. The economics of biophysical equilibrium and moral growth. W.H. Freemann and Company, San Francisco.

DALY, H.E., 1987. The economic growth debate: What some economists have learned but many have not. Journal of Environmental Economics and Management 14, pp. 323-336.

DALY, H.E., 1990. Toward some operational principles of sustainable development. Ecological Economics, 2, pp. 1-6.

DALY, H.E., 1992. Allocation, distribution, and scale: towards an economics that is efficient, just, and sustainable. Ecological Economics, 6, 185-193.

DAWKINS, R., 1989. The selfish gene. Oxford University Press.

FABER, M., Niemes, S. and STEPHAN, G., 1987. Entropy, environment, and resources. Springer, Berlin, Heidelberg.

FABER, M. and PROOPS, J.L.R., 1991. Evolution in biology, physics and economics: A conceptual analysis. In: SAVIOTTI, P. and S. METCALFE (Editors): Evolutionary theories of economic and technological change: present status and future prospects, Harwood Academic Publishers, Manchester, pp. 58-87.

GEORGESCU-ROEGEN, N., 1971. The entropy law and the economic problem. In: DALY, H.E., 1973 (Editor), Toward a steady-state economy, W.H. Freeman and Company, pp. 49-60.

GEORGESCU-ROEGEN, N., 1973. Selections from „Energy and Economic Myths". In: DALY, H.E., 1973 (Editor), Toward a steady-state economy, W.H. Freeman and Company, pp. 61-81.

GOODLAND, R., 1995. The concept of environmental sustainability. Annual Review for Ecology and Systems, 26, pp. 1-24.

HINTERBERGER, F., 1992. Ecological, cultural, and economic evolution and the economy/ecology relationship. In: J.C.J.M. VAN DEN BERGH and J. VAN DER STRAATEN (Editors.), Toward sustainable development: concepts, methods, and policy, Island Press, Washington, pp. 57-81.

HINTERBERGER, F., 1994. On the evolution of open socio-economic systems. In: R.K.MISHRA, D. MAAß and E. ZWIERLEIN (Eds.), On self-organization, Springer Series in Synergetics, 61, pp. 35- 50.

HOLLING, C.S., Gunderson, L. and PETERSEN, G., 1993. Comparing ecological and social systems. Beijer Discussion Paper Series, 36, pp. 1-39.

LOVELOCK, J., 1995. The ages of gaia. W.W. Norton and Company, New York.

LUDWIG, D., 1993. Uncertainty, resource exploitation and conservation: Lessons from history. Science, 260, pp. 17-53.

NORTH, D.C., 1988. Theorie des institutionellen Wandels. Mohr, Tübingen.

O´NEILL, R.V., JOHNSON, A.R. and KING, A.W., 1989. A hierarchical framework for the analysis of scale. Landscape Ecology 3, pp. 193-205.

OSTROM, E., 1990. Governing the commons. The evolution of institutions for collective action. Cambridge University Press.

OSTROM, E., 1993. The evolution of norms, rules, and rights. Beijer Discusion Paper Series, 39, pp. 1-15.

PEARCE, D.W. and TURNER, R.K., 1990. Economics of natural resources and the environment. Harvester Wheatsheaf, New York.

RAUSCHER, M., 1996. Sustainable Development andComplex Ecosystems: An Economist's View. Thünen-Series of Applied Economic Theory 2, pp. 1-15.

SIEBERT, H., 1994. The economics of the environment. Springer, Berlin, Heidelberg.

SOLOW, R., 1974. The economics of resources or the resources for economics. American Economic Review 15, pp. 1-14.

VAN DEN BERGH, J.C.J.M., and NIJKAMP, P., 1991. Operationalizing sustainable development: dynamic ecological economic models. Ecological Economics 4, 1, pp. 11-33.

VON BERTALANFFY, L., 1968. General system theory: Foundations, development, applications. George Braziller, New York.

WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT, 1987. Our common future. Oxford University Press.