5. THE SYSTEMS APPROACH: A CONCEPTUAL FRAMEWORK FOR THE ORGANISATION OF THE CONCEPT OF SUSTAINABLE DEVELOPMENT

5.1 INTRODUCTION

In Chapter 3 it was concluded that there are very different theories on the linkages between the economy, human activities and the environment. Environmental economics emphasises the importance of choices - preservation of the environment costs money and if this option is chosen some other benefits will be foregone. Ecological economic approaches emphasise that ecosystems are subject to natural laws, implying biophysical constraints on economic activities. The neo-institutional school emphasises that the property rights structure is the most important determinant in environmental management; when open access to natural and environmental resources is possible, the definition of exclusive and transferable property rights is the first logical step. In principle the integration of these three approaches is theoretically not that difficult. An objective function such as human welfare is formulated, subject to biophysical and institutional constraints. A major problem in the case of complex and dynamic ecosystems is that the value of biophysical constraints can only be known **ex post**. A recognition of the binding constraints of uncertainty and irreversibilities has led some analysts, working in the tradition of the (co)-evolutionary economic school, to argue for a shift away from optimisation of an objective function subject to a set of constraints, to describing the changing realities or patterns of development (Faber & Proops 1990; Norgaard 1988). Most work in the evolutionary approach has focused on technological progress, invention and innovation, but some work has been done in including biophysical limits over time. In this thesis, the two Arrows of Time are recognised, but no unified theory is presented. One attempt (namely endogenous environmental growth models) is discussed in Appendix A. Despite the useful insights gained by these theories, they remain as good as the **ex ante** specifications, which are based in uncertain dose-damage relationships in ecosystems. These models also do not make provision for asymmetrical definitions of time. The debate on economic growth also suggests that different **a priori** assumptions will determine the relative strength of the two Arrows of Time.

In Chapter 4, the concept of sustainable development was discussed. With the normative character of the term, it has become a catch-all phrase for the theories on the interface between economic efficiency, social equity and ecological sustainability. The unsatisfactory conclusion is that development can be defined to be sustainable or not, depending on the normative criteria, manifesting in weak or strong approaches to sustainable development, which are selected **a priori**. The definition of sustainable development is as good as the theory that is used as the analytical framework.

The objective of this chapter is to provide an organisational framework for the concept of sustainable development that can include both substantivist and processional aspects of reality. This will be attempted through the use of a systems approach. Once such a framework has been created, it could serve as the backbone for the development of economic policy to complex and dynamic environmental problems.

The chapter is divided into two broad sections. In section 5.1 the theory of the systems approach is introduced, and in section 5.2 it is applied to the concept of sustainable development. In section 5.3 some conclusions are presented.

5.2 AN INTRODUCTION TO THE THEORY OF THE SYSTEMS APPROACH

As discussed in section 4.5, the challenge remains to find an approach for economic policy on complex and dynamic environmental problems that has the ability to utilise the best approaches for the most appropriate context – an approach that includes both multiple contexts and elements of change. One approach that takes account of differences over spatio-temporal scales can broadly be defined as the systems approach. The discussion on the systems approach focuses on the following points:

- the concept of systems
- the general applicability of a systems approach
- the character of systems
- the organisation of systems

5.2.1 The concept of systems

There is a substantial literature on systems analysis dating back five decades and more (Ashby 1956; von Bertalanffy 1950; Emery 1972). Systems thinking has been applied to engineering and operational research concepts (Ackoff 1962, 1978; Hall 1962), as a systems approach within a particular subject science (Klir 1960), as a general systems theory to science (von Bertalanffy 1969), and as systems philosophy (Laszlo 1972a). In this study the focus will be on the integrative concepts of systems thinking, and not on the differences in various systems approaches[23].

A systems approach can best be described as the *treatment of wholes* (Angyal 1972:17). The persistent theme in system philosophies is the return from analytical to synthetic philosophy (Laszlo 1972a:3). It is

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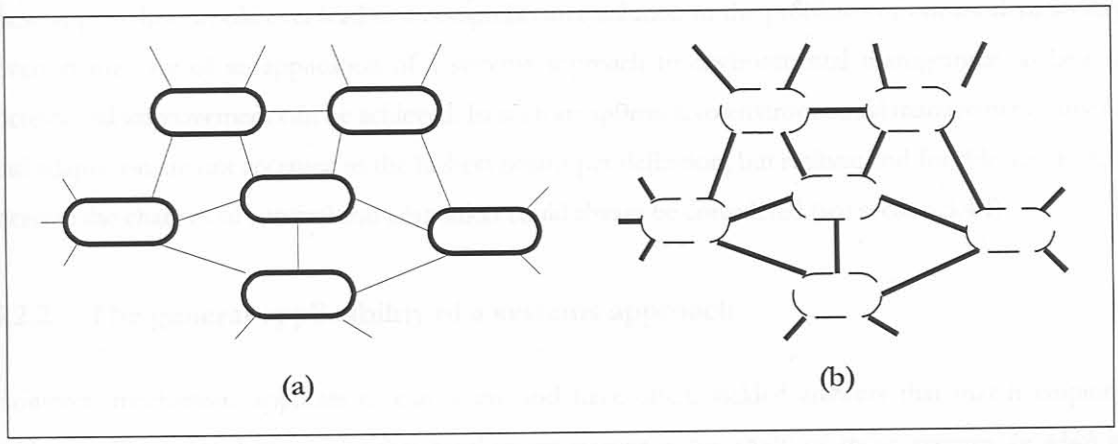
[23] For critical discussions on the differences between systems approaches, see Blauberg *et al.* (1977).

an attempt to overcome the patchwork approach in science and philosophy, a *means of safeguarding ourselves against disaster due to ignorance of systemic interconnections in nature…* (Laszlo 1972a:7) without being *intrinsically … better, nor worse, than attempts at producing special theories* (Laszlo 1972a:10). These special theories are the result of a mechanistic approach to science. The key differences between mechanistic and systemic thinking can best be simplistically illustrated through Figure 5.1. The mechanists' primary enquiry is on the **form** (components) of certain objects (Figure 5.1a), while systems thinkers' primarily enquire about the **pattern linking** these objects and the process of change (Figure 5.1b) (Capra 1997:37). The important point is that the system (or problem) stays the same but there are different ways of dealing with it. While traditional Western science and philosophy use a building as a metaphor of knowledge, systems thinking uses a network as metaphor for knowledge.

Figure 5.1 Objects and relationships



Source: Capra 1997:38

Systems thinking is an approach that incorporates the wholeness of everything. This approach fell into disrepute following scientific reductionism and mechanism that have developed in post-Medieval times.

Capra (1997:17) describes the differences between the systems approach and the mechanistic approach as follows: *The basic tension is one between the parts and the whole. The emphasis on the parts has been called mechanistic, reductionist, or atomistic; the emphasis on the whole holistic, organistic, or ecological. In the twentieth-century science the holistic perspective has become known as 'systemic' and the way of thinking it implies as 'systems thinking'*. The general systems approach has gained momentum in the early twentieth century through developments in quantum theory, organistic biology, gestalt psychology, and the ecosystem concept (Capra 1997). These developments all occurred against a backdrop of traditional science revealing a complexity they were not prepared to deal with. The general systems approach has taken up the task of helping scientists to unravel complexity, technologists to master it, and others to learn and to live with it (Weinberg 1975:3). This search for order and coherence is implicit in any theoretical science, and therefore a systems approach is both a recognition of and an attempt to satisfy these principles underlying and guiding philosophy and science (Laszlo 1972a:12).

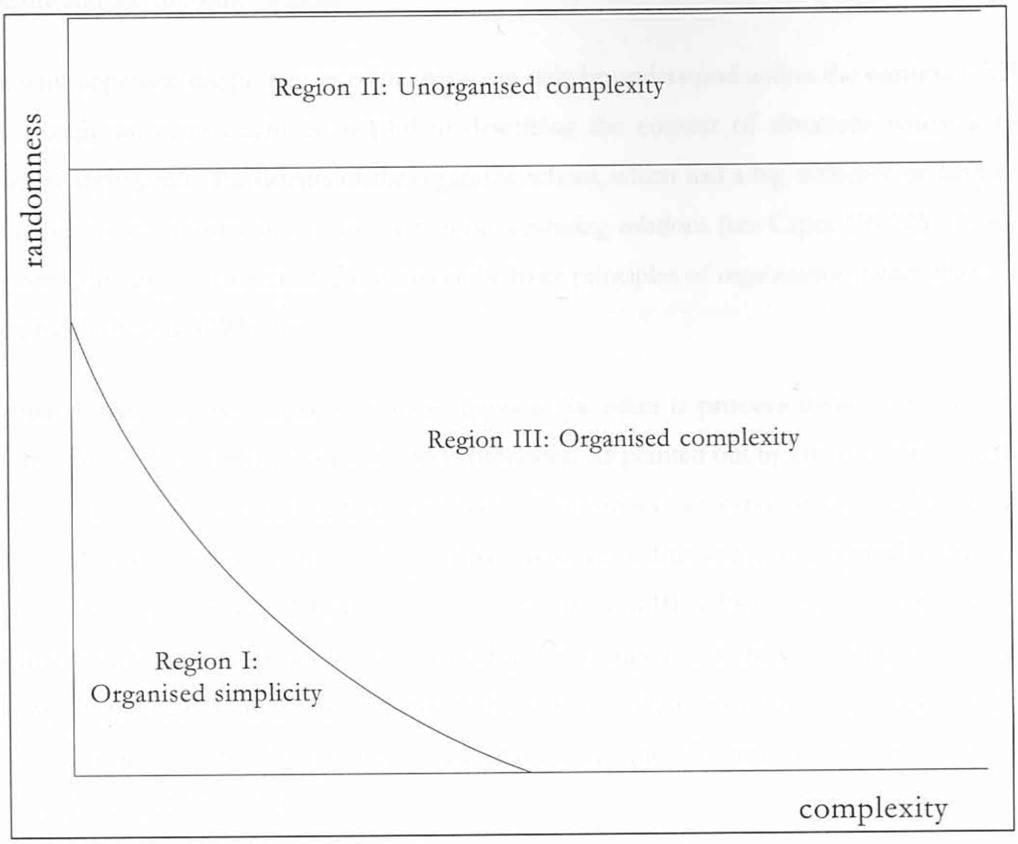
The systems approach, like any other theory or policy rooted in humanistic philosophy, is limited. Laszlo (1972b) argues that the norms to judge the results of a systems approach are internalised in the systems approach itself. Goudzwaard (1982) points out that this type of **internalised ethics** is characterised by the terms **survival or adaptation**. Following Dooyeweerd (1953), Strijbos (1988) points out that this humanist approach embodies fundamental internal tensions between the ideal of individual freedom and science's urge to control. The role of humanist thinking is not only to change and re-focus the scientific ideal to the new developments in science, such as systems thinking, but also to harmonise the scientific ideal of total control and the individual ideal of freedom (Strijbos 1988:51). Neither the traditional mechanistic science with its antropocentrism, nor systems theory, with its cosmocentrism, is able to accomplish this, as the heart of the problem lies in the humanistic point of departure itself. The important implications for this study are that the results of both traditional science and systems approaches can be fruitfully used, but with the recognition that none of these approaches, nor a mix of these approaches, would ever lead to a comprehensive solution to the problems of our modern society. Even in the case of an application of a systems approach to environmental management, at best an incremental improvement can be achieved. In such an approach to environmental management, survival and adaptation are not accepted as the highest norms per definition, but realistic and feasible actions that increase the chances of survival and adaptation could always be considered (see section 3.4.1).

5.2.2 The general applicability of a systems approach

However, mechanistic applications can often, and have often, yielded answers that match empirical evidence. The point, however, is that mechanistic science is the study of those systems *for which the approximations of mechanics work successfully* (Weinberg 1975:5). Mechanistic thought is a simplification that serves well at certain times, at certain scales of observation and for certain purposes, but not so well or not at all, in other situations.

When is a mechanistic approach useful and when is a systems approach warranted? Is there a well-defined boundary between the two? To answer these questions, a short detour in the historical development of science might shed some light. The history of scientific paradigms for mathematical modelling is used as an example to illustrate the development of science in general. Up to Poincare's development of dynamical systems (see Stewart 1990:57-72), science fell into two broad paradigms: first, high-precision analysis by way of differential equations, the mathematics of deterministic processes, in practice only applicable to a few relatively simple and well-structured problems. The second was the statistical analysis of averaged quantities, the mathematics of stochastic processes; applicable to complex systems, but sufficiently random in their behaviour and sufficiently regular to be studied statistically (Stewart 1990:54; Weinberg 1975:16). Stewart (1990:54) describes the situation as: *…two mathematical ideologies, each applying only within its own sphere of influence. Determinism for simple systems with few degrees of freedom, statistics for complicated systems with many degrees of freedom.*

Figure 5.2 Place of scientific paradigms



Source: Weinberg (1975)

Figure 5.2 illustrates this distinction. Following Weinberg (1975), a mechanistic, analytical approach is useful in the cases of both low randomness and low complexity, while a statistical approach is used in situation of high randomness. The **organised simplicity** (Region I) is the region of mechanism. **Unorganised complexity** (Region II) is the region of aggregates. Region III, the gap in the middle, is the region of **organised complexity** – *a region too complex for [mechanistic] analysis and too organised for statistics. This is the region of systems* (Weinberg 1975:19).

Region III is complying to the **Law of Medium Numbers** (von Bertalanffy 1969; Weinberg 1975:19)[24]. This means that small numbers can be solved by analysis, large numbers can be approached through aggregations and statistical techniques, but medium numbers cannot be handled by either one of these approaches. An illustration of Weinberg's regions is that the economy, like any other social system, is subject to **regions of time**, within which the parameters of the system are fairly stable, but at the boundaries of which the parameters change. Econometric analysis, therefore, is only useful within a

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[24] Illustrating our (unknowing) familiarity with this law, this law is nothing else than what we call Murphy's Law: anything that can happen, will happen (Weinberg 1975:20).

particular region of time (Boulding 1991:15-16). The boundaries are the dividing lines between organised complexity and the two other regions.

In a systems approach the properties of the parts can only be understood within the **context** of a bigger whole. Rough analogies might be helpful in describing the context of situations where a systems approach is appropriate. Exponents of the organistic school, which had a big influence on later systems thinking, believe in the analogy of organisation or organising relations (see Capra 1997:25). This means that systems thinking is contextual, focusing on the basic principles of organisation rather than on basic building blocks (Capra 1997:29).

Contextual thinking is one strand of systems thinking, the other is **process** thinking (Capra 1997:42). Every structure is a manifestation of underlying processes. As pointed out by chaos theorists, in the case of open systems processes need not be deterministic. This implies that a state at a particular time will not explain the state at a particular time in future. Chaos is all around us and just as normal as deterministic behaviour (Cohen & Stewart 1994:210). For example, in Region III of Figure 5.2 it can therefore not be stated that today's indicators for the sustainability of ecological systems could be used to explain tomorrow's ecological systems. As pointed out by Odum (1953), ecosystems are open-ended flow processes, driven by a myriad of factors. Small changes in (one of) these factors can lead to entirely different patterns and processes.

In summary, science cannot deal with all systems. The reductionist scientific approach is useful in many instances, but is often applied in the extremes of partial analysis. It is also expected that the systems approach will not be able to control medium number cases as rationally as we would like them to. Science is often limited by the philosophical underpinnings of techniques restricted to systems of small and large numbers (see Weinberg 1975:22). Weinberg (1975:31) stated that …*it is important not to stop with rough analogy when the occasion demands that we go on, but to render the analogy in a precise, explicit, and predictive model.* A systems approach can shed light on the context of a problem and explain the underlying processes, while an application of a reductionistic approach can benefit from better defined time and space boundaries. Whether a particular application of these scientific approaches is useful can only be judged according to the purpose it is designed for (Weinberg 1975:62).

In summary, Bossel (1986) defined three related general system concepts:

- A system consists of one or more structurally connected elements whose states are influencing (or dependent on) each other or on themselves (i.e. linkages).
- A systems has a purpose, or it is possible to ascribe a purpose to it (i.e. (teleological) process).
- A system has a system boundary separating it from the system environment (i.e. context).

The three words distinguishing a systems approach from more mechanistic approaches are therefore linkages, processes and context.

5.2.3 The character of systems

To understand the character of systems some concepts need to be discussed:

Open and closed systems

Closed systems have unchanging components eventually arriving at a state of equilibrium. Open systems exchange flows with their environment in the form of matter, energy or information (Clayton & Radcliffe 1997:20).

Living and non-living systems

All living (natural and social) systems are open systems, in contrast to non-living (physical) systems. Within living systems, there are three additional requirements: firstly, the interacting components are linked in an organised manner; secondly, participating components are affected by their own participation and modified when leaving the system; and thirdly, the system behaves as a whole (Clark, Perez-Trejo & Allen 1995:21). Living systems require a continuous flow of energy and matter to maintain their existence. These causes and effects between these flows of energy and matter are complex because they are non-linear (Clayton & Radcliffe 1997:37-40). The cumulative impacts, through the interaction of feedback mechanisms, are important for policy making in living systems.

Hard and soft systems

In contrast to a soft system, in a hard system the objective is well known and well structured (Checkland 1981). A soft systems approach should be regarded more as a contribution towards problem solving, rather than a goal-directed methodology. A hard systems approach can be used when dealing with structured problems (such as engineering applications), while a soft systems approach is needed when dealing with unstructured problems (such as complex environment-economy systems), meaning that the definition and the designation of objectives is in itself problematic (Clayton & Radcliffe 1997:186). The soft systems approach focuses *on a set of principles (methodology) which guide action in 'trying' to manage (in the broad sense) real-world problem situations; it is systems-thinking-based and is applicable to taking purposeful action to change real situations constructively* (Checkland & Scholes 1990:5).

Checkland & Scholes (1990) quote Schon (1983:42-44) in describing the need for a soft systems approach to policy-making issues: *Unfortunately, although there is a 'high, hard ground where practitioners can make effective use of research-based theory and technique', there is also a swamp lower down in which lie the 'confusing "messes" incapable of technical solution'; and it is in the swamp that we find 'the problems of greatest human concern'. Schon points out the emergence of many attempts to turn 'soft' problems into 'hard' ones via computerised models, and rightly points out that in spite of successes in 'undemanding areas' such as inventory control and logistics the algorithms '… have generally* *failed to yield effective results in the more complex, less clearly defined problems of business management…'.* The management of the state's business, namely policy making, could even be more complex and less clearly defined, a topic further discussed in subsequent chapters.

Spatio-temporal scales and resolution in systems

It cannot be assumed that systems operate the same on different spatio-temporal scales and at different resolutions. Systems are characterised, amongst others, by an inability to simply 'add-up' small-scale behaviour to arrive at larger scale results (von Bertalanffy 1969; Costanza 1993:29). The dynamics of systems are strongly influenced by the spatial patterns of their components. A study on the interaction between system components over time and space scales could explain, to some extent, the strength and nature of these internal feedback mechanisms[25].

The spatio-temporal scales and number of components in a particular system are referred to as the resolution (or grain) of the system (Costanza 1993:36). A higher resolution increases the data predictability, but at the expense of overall model predictability. The challenge is to find an optimal resolution for the systems model in question.

System classification

The choice of system variables, and the spatio-temporal scales used for their description, is ultimately a function of the questions asked (Clark, Perez-Trejo & Allen 1995:27-28). If a system is defined for the purpose of national level policy making, an approximation of variables on lower spatial levels is needed to avoid unnecessarily complex models. This differentiation over space and time and the problem-solving approach of the systems approach, illustrates the point that an understanding of a system will always be an incomplete process (Clark, Perez-Trejo & Allen 1995:28).

Systems change and transformation

In Chapter 3 the two Arrows of Time were introduced, in short referred to as entropy and innovation. Unpredictable processes are those where the goals are not known, thus where novelty is emerging over time (Faber & Proops 1990:73). The end-goal of entropic processes could in principle be derived, but over some spatio-temporal scales the calculations of the exact levels of energy loss over time might not justify the costs of doing so. Some innovations may be more predictable than others, but no optimal choice can be made **ex ante** as all the alternatives are not known. The structure or organisation wherein optimal levels can be calculated is continuously subject to change and transformation. In the study of

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[25] Hengeveld (1982) illustrates the importance of spatio-temporal scale in ecological research using the case of carabid beetles in Europe and more specifically in The Netherlands. Hengeveld found that problems arise when different scales are compared; the results of a particular study cannot be generalised to other scales of analysis. Ecologists, however, usually do not account for differences in spatial and temporal scales in their models and theories; those are usually formulated in general terms, independent of the levels of variation (Hengeveld 1982:1).

systems one has to take both the elementary component and changing organisational levels into account. Clark, Perez-Trejo & Allen (1995:29) argue that *'science' should aim at understanding the relation between these levels if it is not to be trivial.* The capacity to change becomes an important policy variable in living systems as they have to cope with change and transformation per definition.

System behaviour: stability and resilience

The appropriate characteristic for system sustainability is not resolved in ecological debates. The debate centres on function behaviour and organisation in ecosystems. In terms of the function of ecosystems two kinds of behaviour, namely, **stability** and **resilience** and the place of the terms complexity and diversity are highlighted in this debate (Holling 1973, 1986; Patten 1998). The four **ecosystem functions** are exploitation, conservation, creative destruction and renewal (Holling 1986). The behaviour of these ecosystems are discussed according to the terms stability and resilience. Stability represents the ability of a system to return to a state of equilibrium after a temporary disturbance; the more rapidly it returns and the less it fluctuates, the more stable it will be. Stability emphasises equilibrium, low variability, and resistance to and absorption of change. In contrast, resilience is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables. Resilience emphasises the boundary of a stability domain and events far from equilibrium, high variability, and adaptation to change (Holling 1986:296-297, 1973:14)[26].

Complex systems

Complexity can be defined as the **interconnectedness** between different components in a system. O'Neill *et al.* (1986:41) argue that complexity increases when the number of components and thus the linkages within a system increases. It was long argued in the ecological literature that more species and more interaction between them conferred more stability, because more connections mean more pathways for the movement of energy and nutrients (see Holling 1986:308). However, this view of complexity is limited. Following Weinberg's analysis of the area of systems applicability (see Figure 5.2), both complexity **and randomness** define the *type of complexity* (O'Neill *et al.* 1986:44) or *degree of connectedness* (Holling 1986:308), which really should be the study objective of the systems researcher. In a non-randomly connected complex system (i.e. a system with, in principle, a known **telos**), such as ecosystems, this means that we are in Weinberg's Region II: organised complexity. In conclusion, not all increased connectedness is a good thing – the **type of complexity** is important in the understanding of systems.

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[26] Another definition takes resilience as a measure of the speed of the system's return to equilibrium (see Pimm 1991). However, in terms of the exploration of evolutionary pathways, resilience extends beyond such a measure of return time (Clark, Perez-Trejo & Allen 1995:23). Most work in the area has continued to focus on the Holling-definition of resilience (Perrings 1998:504).

Complexity, stability and resilience in systems

What does this changed definition of complexity mean for the interpretation of the complexity-stability and complexity-resilience links? To answer this question the concept of diversity needs to be highlighted, since diversity is often seen as a measure of complexity in the system. Capra (1997) identified diversity as a principle for systems. The diversity-stability literature never progressed beyond wrestling with definitions of diversity and stability (Patten 1998:99). (For earlier accounts see Woodwell & Smith (1969) and MacArthur (1955)). May (1971) indicates that increased diversity would in general lower the stability of randomly connected networks. A stable system is also not necessarily a resilient system. Systems with low stability can often demonstrate high resilience (Holling 1986:308). Evidence on the diversity-resilience is also limited, but there is some evidence that uniformity – the opposite of diversity – is producing non-resilient economic systems (Pearce 1998:47), but this is also highlighted as an area for further research (Perrings & Pearce 1995). There is no conclusive outcome on linking complexity through diversity to either stability or resilience.

5.2.4 The organisation of systems

Both the characteristics of systems and the way systems can be organised are important for systems approaches to policy for complex and dynamic environmental problems. Complex systems imply the existence of many connections across spatio-temporal scales. This means that the study of systems not only needs concepts of function, but also of organisation – the way elements are connected within subsystems and the way subsystems are embedded in larger systems (Holling 1986:296). Developments in this subfield are connected to hierarchy theory (Pattee 1973; Simon 1973). Through the integration of the concepts of stability, resilience and hierarchy theory, a framework for comprehending organisational change can be outlined (Allen & Starr 1982; O'Neill *et al.* 1986)[27]. Such a framework could prove to be useful for developing a conceptual framework to organise economic policy-making approaches to complex and dynamic environmental problems.

Hierarchy theory is an attempt to frame the organisation of ecosystems. Simon (1973:5) describes that in the application to the architecture of complex systems, hierarchy simply means a set of Chinese boxes of a particular kind[28]. Hierarchy is all around us: one hierarchy runs from living organisms, to tissues and organs, to cells, to macromolecules, to organic compounds, to molecules, to atoms, to protons and electrons and within the protons to quarks. Hierarchy theory is a useful organisational framework in a

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[27] If systems are subject to homeostatic control, organisational change could take place. An example is that the living body of humans and most animals regulate an endothermic temperature of 37°C, a few degrees away from death, but ensuring the greatest range of external activity (Holling 1986:295). To include this change in the management of a system, one needs to understand the way the system is organised. For instance, before a fever can be controlled within certain acceptable risk boundaries one needs to understand the organisation of the living body.

[28] A set of Chinese boxes usually consists of a box enclosing a second box, which in turn encloses a third, etc.

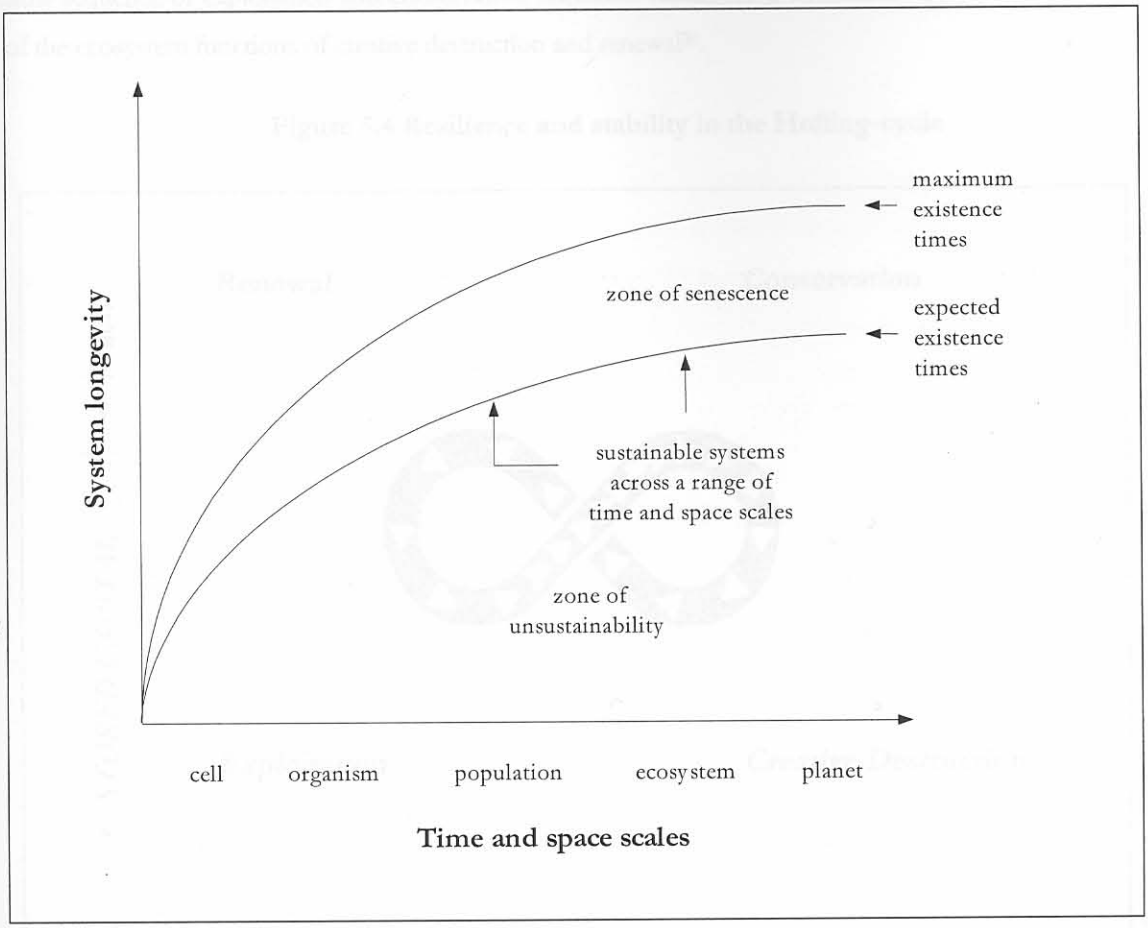
world where everything is connected to everything else. Simon (1973:23) describes the need for hierarchical organisation: *Everything is connected, but some things are more connected than others.*

One example of hierarchical organisation is to evaluate a system on the basis of the existence times of its components. In an attempt to comprehensively formulate the concept of sustainability with the use of the hierarchy relationships between a part (component) and a whole (system), Patten (1998) analyses the sustainability of systems with respect to three attributes: stability, continuation and longevity. The main conclusions are:

- Systems stability is necessary, but not sufficient for sustainability. A stable system can be unsustainable for other reasons. Not mentioned by Patten (1998), but following from the previous discussion, one of these reasons could be the lack of resilience.
- Component stability is sufficient for systems sustainability. Systems with unstable components can be made sustainable through internal design characteristics. Following Ashby (1956), stable systems comprising unstable components are commonplace in system theory. Systems have an internal redundancy and feedback control mechanism. This implies that whole systems would appear to have existential priority over their component parts (Patten 1998:99-100).
- Continuation of a system, within established behavioural norms over time is sufficient, but not necessary, for sustainability.
- Continuation of the components of a system, within established behavioural norms over time, is sufficient for both component and system sustainability.
- A system is sustainable if and only if it persists in nominal behaviour states as long or longer than its expected natural longevity or, in case of non-living systems, its existence time.
- Neither component, nor system-level sustainability, as assessed by the longevity criterion, confers sustainability to the other levels.

Patten (1998) concludes that neither stability nor continuity, but longevity is the only criterion that is sufficient and necessary for system sustainability. It is possible to organise a system according to the expected existence times of its components, as illustrated in Figure 5.3. The difference between the maximum existence time of various organisational forms and the expected existence time is the zone of senescence, or the zone of growing old. This zone gives an indication of the relative unsustainability of the system under observation.

Figure 5.3 The organisation of systems based on existence times



Source: Patten (1998:103)

The important point is that sustainability is primarily a temporal aspect, one that cannot be constructed on spatial grounds alone. Although it would be difficult to translate relatively exact existence times of socio-cultural and economic systems, it is a powerful concept of thought.

Holling (1986:307) attempted to integrate function (resilience and stability) and organisation into one model by explaining the full dynamic behaviour of ecosystems at an aggregate level, which can be represented by the sequential interaction of four ecosystem functions: exploitation, conservation, creative destruction and renewal (see Figure 5.4)[29]. This ecosystem cycle is a process of slowly increasing organisation or connectedness (from exploitation to conservation) accompanied by gradual accumulation of capital. There is empirical evidence that species diversity would lead to an increase in the productivity of ecosystems (i.e. accumulation of capital) (Naeem *et al.* 1994). At first, stability increases, but the system becomes over-connected, triggering rapid change (conservation to creative destruction). The stored capital is released and the degree of resilience is determined by the balances

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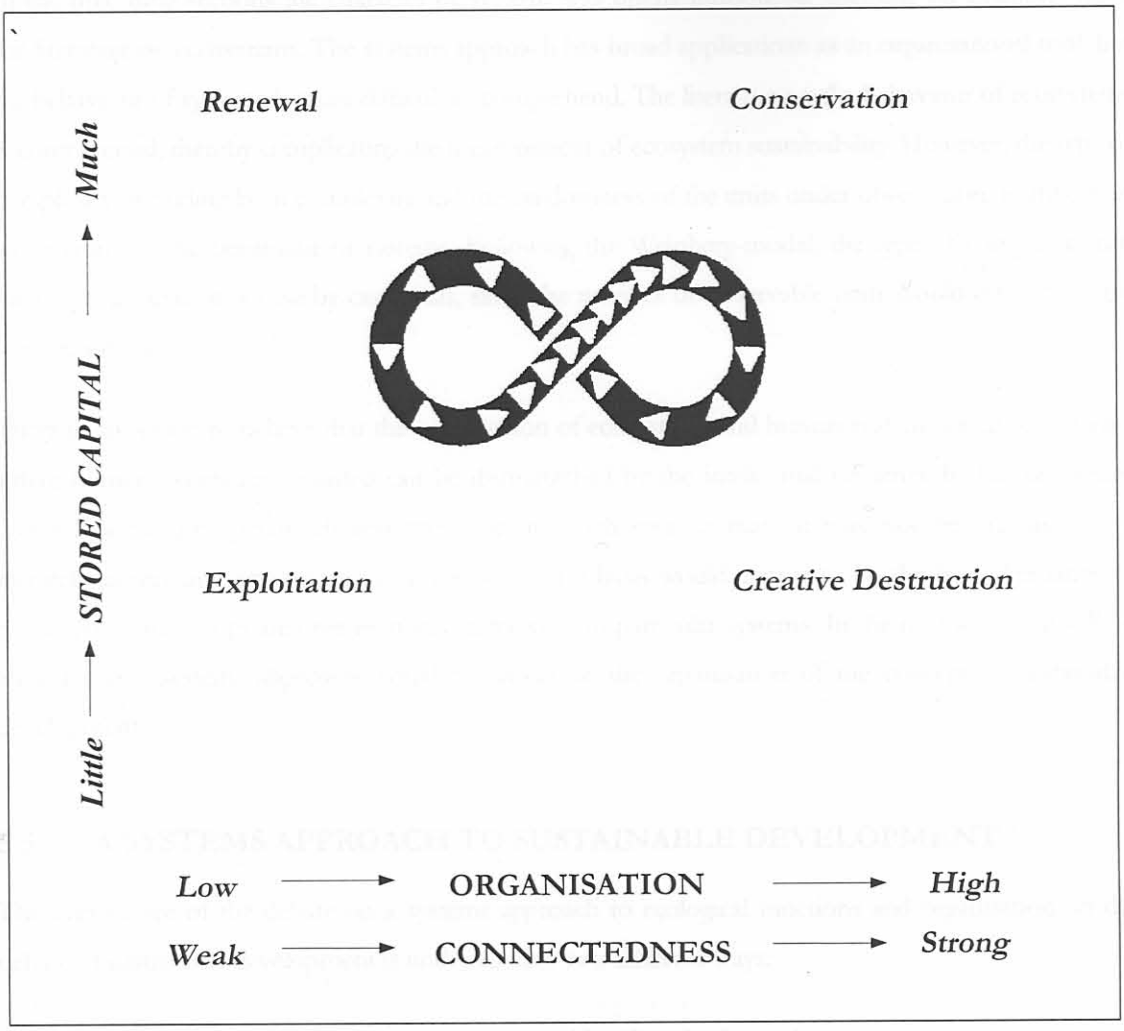
[29] The Holling-model is cited widely to describe the change in ecosystems; see for example Barbier *et al.* (1994); Clark, Perez-Trejo & Allen (1995); Krishnan *et al.* (1995).

between the processes of mobilisation and retention. Stability and productivity are determined by the slow sequence of exploitation and conservation sequence. Resilience is determined by the effectiveness of the ecosystem functions of creative destruction and renewal[30].

Figure 5.4 Resilience and stability in the Holling-cycle



Source: Holling (1986:307).

Following Allen and Starr (1982) and a subsequent analysis by Holling (1986), it seems that the integration of organisation and function needs to take into account the fact that system hierarchies are not static in the type or strengths of connections. It is a balance between the forces of instability, due to over-connectedness, and renewal, embodying the resilience of the system. It might happen that the

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[30] Some natural disturbances, such as events triggered by fire, wind and herbivores are part of the internal dynamics of ecosystems and seem to be crucial for ecosystem resilience and integrity (Barbier *et al.* 1994:25).

system collapses, thereby escaping to a different stability domain. This can happen if a process of mobilisation is not balanced by a process of retention.

5.2.5 Learning from ecosystems

In the preceding sections the character of systems was briefly introduced, focusing on examples from the literature on ecosystems. The systems approach has broad applications as an organisational tool, but the behaviour of systems is more difficult to comprehend. The literature on the behaviour of ecosystems is controversial, thereby complicating the measurement of ecosystem sustainability. However, the type of complexity, including both complexity and the randomness of the units under observation, is important when studying the behaviour of systems. Following the Weinberg-model, the type of complexity can only be evaluated on a case-by-case basis, since the number of observable units would differ per case (see section 5.2.2).

There is no reason to believe that the organisation of ecosystems and human systems are alike. Systems where human beings are included can be distinguished by the intellectual influence by human beings themselves on the system wherein they operate. Such systems may or may not be organised in a hierarchical way and an evaluation on a case-by-case basis would appear to be the best alternative to enforcing an inappropriate organisational framework to particular systems. In the next section it will be argued that a systems approach would contribute to the organisation of the concept of sustainable development.

5.3 A SYSTEMS APPROACH TO SUSTAINABLE DEVELOPMENT

The importance of the debate on a systems approach to ecological functions and organisation on the debate of sustainable development is understood in two different ways:

- A better understanding of ecosystems could at best lead to a better economic assessment of choices (Pearce 1998; Commonwealth Secretariat 1999).
- The character of systems in general is important for understanding the component functions and to organise a sustainable development system (SDS) (see Perrings 1998; Arrow *et al.* 1995; Turner *et al.* 1996; Perrings *et al.* 1997; Clayton & Radcliffe 1997; Ayres 1998; Froger & Zyla 1998; Stewen 1998; Köhn 1998; Musters *et al.* 1998; Duchin 1996).

Pearce (1998:47-48) and Perrings and Pearce (1995), arguing from the perspective of the capital-theory approach, state that the ecological literature on the diversity-resilience link suggests further support for the precautionary principle. Biodiversity is thereby seen as natural capital that can or cannot be substituted for other types of capital, but it still does not address the question of the opportunity costs of doing so. Those costs could be significant as many livelihoods depend on the exploitation of biodiversity in ecosystems. The crucial trade-off is, that if diversity and resilience are essential for ecosystems sustainability, it is not compatible with the well-being of the poor (Pearce 1998:48). The concept cannot be readily included in standard economic theories on sustainable development, mainly because of the following:

- Resilience has not been quantified by ecologists, therefore monetary valuation, at least needed for operationalising the weak approach to sustainable development, is not possible (Lange 1999:30).
- The complex, dynamic system approach underlying the concept of resilience is hard to internalise in the concept of property rights (Hanna *et al.* 1996:xiv). It is impossible to attach well-defined property rights to an immeasurable system characteristic.

It is therefore argued that the sustainability-as-resilience concept is more of a research agenda than a policy-relevant statement of immediate use (Commonwealth Secretariat 1999:1.12).

However, this approach takes the capital theory component of the ecological economic approach (strong sustainability) as the starting point. Without excluding the relevance of this approach in some situations of policy making, the character of systems itself is important in understanding the component functions and organisation of a SDS. In Chapter 4 it was concluded that a more integrative approach is needed to study the sustainable development of a particular spatial area, such as a country. In this section the discussion focuses on the following issues:

- Why a systems approach to sustainable development?
- The character of a system for sustainable development
- The organisation of a system for sustainable development

5.3.1 Why a systems approach to sustainable development?

Economic, ecological and socio-cultural sustainability on its own would not guarantee sustainable development. The definitions of sustainable development in ecology and economy can provide insights for an integrative framework, but are not sufficient on its own. Ecological concepts of sustainability focus on the implicit capacity to adapt to the stresses imposed on an ecosystem by its interdependence with other systems. This physical concept of ecological sustainability (or **Holling-sustainability**), admits the functioning of ecosystems within the boundaries of the organisational parameters of the systems (Common & Perrings 1992). This sustainability rule comes closest to the ecological economic interpretation of strong sustainability. Every category of capital should be sustainable in its own right. There are no trade-offs allowed with natural capital protected by safe-minimum or absolute standards. However, neither Holling-sustainability nor the ecological economists' version of strong sustainability provides a comprehensive account of sustainable development. Holling-sustainability abstracts from human needs and preferences, equity requirements and economic efficiency conditions. Ecological economics (i.e. strong sustainability) neglects the complexity and dynamics of a system of sustainable development and the requirements of economic efficiency (after Hediger 1997:104-105).

The economic approach to sustainable development has been described as **Solow-sustainability**, based on the Golden Rule of neoclassical growth theory (Solow 1992a) (see section 4.4.1). This environmental economic sustainability (i.e. weak sustainability) is blind to the physical properties of dynamic ecological-economic interactions (Common & Perrings 1992). It also requires an equitable intra-generational initial stock of capital big enough to support a decent standard of living. It is assumed that the economy receives free gifts from the environment (as a source of natural resources and as receptor of pollution and waste). While Holling-sustainability takes a more macroscopic systems view, Solow-sustainability considers only one component of the system for sustainable development, namely the economic system (Common & Perrings 1992).

Socio-cultural sustainability often focuses narrowly on population growth as the key force disrupting sustainable development (Ehrlich & Ehrlich 1991). However, various institutional factors governing access to the resources can play a major role in moving towards or away from sustainable development (see Leach, Mearns & Scoones 1997; North 1990). This dynamic approach, based on the relative costs of (environmental) entitlements and institutions, provides answers to previously neglected areas in the Holling and Solow approaches to sustainability. However, biophysical limits and economic efficiency considerations are not directly taken into account by this approach.

Sustainable development is bigger than the sum of its ecological, economic and socio-cultural sustainability parts. Sustainable development is not the same as sustainability. Even in the case where economic, ecological and social sustainability is achieved, it does not follow per definition that sustainable development is achieved. An integrated approach, incorporating all the key principles of sustainable development, is needed (Hediger 1997). It is apparent that not one of the basic sustainability principles is sufficient on its own to achieve sustainable development.

How do the dimensions of sustainable development relate to each other? Various sub-disciplines such as economics, ecology, social and developmental studies and philosophy contribute to the sustainable development debate. However, this frequently leads to a largely unproductive debate, where actors tend to support the positions of their particular disciplines (van Jaarsveld 1996:37; Serageldin 1996). It is clear that the various components of sustainable development are closely linked to each other. This requires an integrated approach to defining a system of sustainable development. Hediger (1997:106) concludes that an analysis of sustainable development should be extended from an economic and ecological approach to the social context provided by institutional and (co)-evolutionary economic approaches.

An integrated approach to sustainable development would therefore require some synthesis between weak and strong sustainability. Trade-offs between different concerns of sustainability should become possible. This means that an integrated framework is formulated in some kind of value principle, which is extended to include some physical principles in order to comply with the carrying capacity and integrity of global ecosystems (Hediger 1997).

Besides an effective integration of economic, ecological and social factors, an integrated approach must also take account of the dynamics of a sustainable development system. As implied by the word development, sustainable development is in a process of continuous change. The passage of time includes novelty and unknown goals, as emphasised by the evolutionary approaches to economy-environment interactions.

5.3.2 The character of a sustainable development system

Sustainable development can best be described as a complex, dynamic system. The combination of substance and process is embodied in the concept of a complex, dynamic system. Substance can be complex as well, but process is always dynamic. The system is complex in the sense of the number and intensity of the interrelationships between components, and dynamic in the sense of real-world changing realities and continuous transformation. The nature of a sustainable development system (SDS) can be described as follows (de Wit & Blignaut 2000):

- The SDS is an **open system** as matter and energy flow between the economic and ecological subsystems, and information and knowledge between the socio-cultural, economic and ecological subsystems[31].
- The SDS is a **living system** as the interaction between human beings and ecosystems are studied. Some sub-components are non-living, such as natural resources (minerals, fossil fuels) and ecosystem services (clean air, mountain scenery), but the organisation and use of these non-living components are ultimately done by human beings.
- The SDS is a **soft system** as sustainable development cannot be defined **ex ante** with an appeal to a scientific truth-value. The criteria for sustainable development are understood differently in various (economic) theories on sustainable development. In some cases, sustainable development could be defined as a harder system when the problem is relatively simple and well defined and where objectives are well structured. Such an approach could only

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[31] Information and knowledge can serve as inputs in economic processes, but also in non-economic processes, such as the appreciation of nature's beauty.

be helpful on the analysis of sustainable development on smaller spatial and shorter temporal scales, such as the sustainable development of a particular firm in the short term[32].

- The SDS reveals the **tension** between **spatio-temporal scales** for economic and ecological subsystems. All economic and ecological changes have dimensions in both space and time (Lunney *et al.* 1997:135), although very different (Ring 1997:237). These changes are, however, based on different organisational principles in, amongst others, space and time. The material and value-orientated facets of production and consumption leads to the homogenisation of time and space in a capitalistic economy (Altvater 1994). Economic activity can be described in two ways: (i) as the transformation of matter and energy and (ii) the creation of a surplus which is measured in money units (Altvater 1994:80). The latter description is arguably perceived to be the most important in current capitalist societies, but in many instances the coordinates of production are still defined in terms of physical time and physical space. The emphasis on the creation of a surplus have led to a shortening of economic activities (time is money) and the removal of quantitative and qualitative impediments in space, or in other words: globalisation. The environment, in contrast, has irreducible dimensions in time and space, mainly due to relative slow time rates of ecological production and differentiated spatial structures, especially for terrestrial ecosystems (Ring 1997). The relative slow rate of ecological change relative to economic activity and geographical characteristics are not included in standard economic analysis (Lange 1999:30). The question is to what extent these different systems can be integrated. Altvater (1994:82) even argues that ecological crises can, in many regards, be understood in terms of the collision between spatio-temporal interpretations. A discussion on the linkages between economic and environmental interactions therefore needs to take this spatio-temporal collision between economic and environmental systems into account.

- The **classification** of the SDS is a **function of the problem at hand**. The resolution (space, time and number of components) needs to be defined **ex ante**, before a systems analysis could be performed. If a problem is defined on a national level a detailed economic resolution (detailed micro-economic behavioural models) would be at the expense of model predictability or description, while the omission of ecological and socio-cultural concerns would be at the expense of the system definition itself. If the focus is on national policy making, a layered approach can be used to model the SDS on a national level, before subsystems can be defined and modelled at another resolution to aid the actual implementation of recommendations.

- The SDS in itself is in a **process of change**. The important question is whether this change can be modelled as risk or whether it should be treated as novelty. On the component-level the chances are greater that some processes do have known probabilities, but on the level of a

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[32] In the Weinberg-model this situation is described in Region I (see section 5.2.2).

change in SDS itself (change at the organisational level) the dynamic, novel character of change is applicable. Any optimisation procedure that neglects the sustainability of the overall system will fail to account for the dynamic and evolutionary effects of sustainable development (Turner *et al.* 1996).

- This change is a continuous interplay between the stability and the resilience of the SDS. The **degree and type of connectedness** become important variables for understanding the dynamics of the SDS. The Holling-type of continuous structural change is not entirely new to the study of economic systems. The accounts of Kuznets (1959) and Schumpeter (1934, 1939) have become standard references in explaining long-term economic growth patterns. These economic approaches presented the notion of equilibrium in a more sophisticated way, but without accounting for dynamic systems far from equilibrium (Clark & Juma 1987). Clark, Perez-Trejo & Allen (1995) suggested that a class of simulation techniques, based on spatial, integrative economy-environment modelling, to study the complex and dynamic behaviour of economic systems, is needed[33].

The complex, dynamic character of the SDS has important implications for the design of economic policy towards such problems, an issue which will be further discussed in Chapter 7.

5.3.3 The organisation of a sustainable development system

In Chapter 4 the three elements of sustainable development were introduced: the economic, ecological and socio-cultural systems. Sustainable development can only be understood if the relations between the ecological, economical and socio-cultural systems are known. These relations could be separate, interdependent or nested systems in a global hierarchy (Köhn 1998). The hierarchy theory is only applicable to the organisation of sustainable development when one system is nested within another system. It will be demonstrated that this (often implicit) organisation of sustainable development lies at the heart of the polarisation in the debate on the best approaches to economic policy on complex and dynamic environmental problems.

The applicability of these organisational approaches to sustainable development would depend on the spatio-temporal scale of analysis and the realities of the economic process. On a local scale, with adequate provision of raw materials and no negative environmental or social feedbacks, sustainable development can be defined around the criteria for economic efficiency. On another scale, say with adequate provision of raw materials, negative environmental feedbacks, but no negative social feedbacks, sustainable development can be defined around the criteria of ecological scale and economic efficiency. How sustainable development is perceived, on which level it should be steered and the flows of inputs

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[33] Clark, Perez-Trejo & Allen (1995) applied this model to the Crete economy.

and outputs into, through and from the system are all elements to be described in the **ex ante** definition of the system.

The debate on the organisation of a SDS recently polarised around a **hierarchical approach** (Daly 1992, 1999; Weston & Ruth 1997; Peet 1992) and an approach of **co-evolutionary interdependence** (Stewen 1999, 1998; Duchin 1996). The hierarchical approach is derived from the literature on the organisation of ecosystems, while the approach of co-evolutionary interdependence emphasises the importance of trade-offs in political or market processes in the SDS.

This debate can best be illustrated with the aid of a few figures. In Figure 5.5 three organisational possibilities to the concept of sustainable development are illustrated, namely nested, interdependent and iterative nested and interdependent. Figure 5.5a illustrate a situation of **nested subsystems**: the economic system is subject to the constraints of the socio-cultural system, where both are subject to the constraints of the ecological system[34]. Köhn (1998:183) refers to this situation as the three-level hierarchy. This organisation of sustainable development will be appropriate if

- there are biophysical limits to production and consumption (ecological constraints), and/or
- ethical and social limits to production and consumption (socio-cultural constraints), and/or
- property rights structures impose a constraint on production and consumption (socio-cultural/economic constraint).

This organisation correlates best with the CTA, and more specifically, with the strong sustainable development approach. Daly (1999, 1992) suggests a **logical sequence** where a planner defines first, the optimal scale, second the optimal distribution, and only in the third place market processes to define an optimal allocation.

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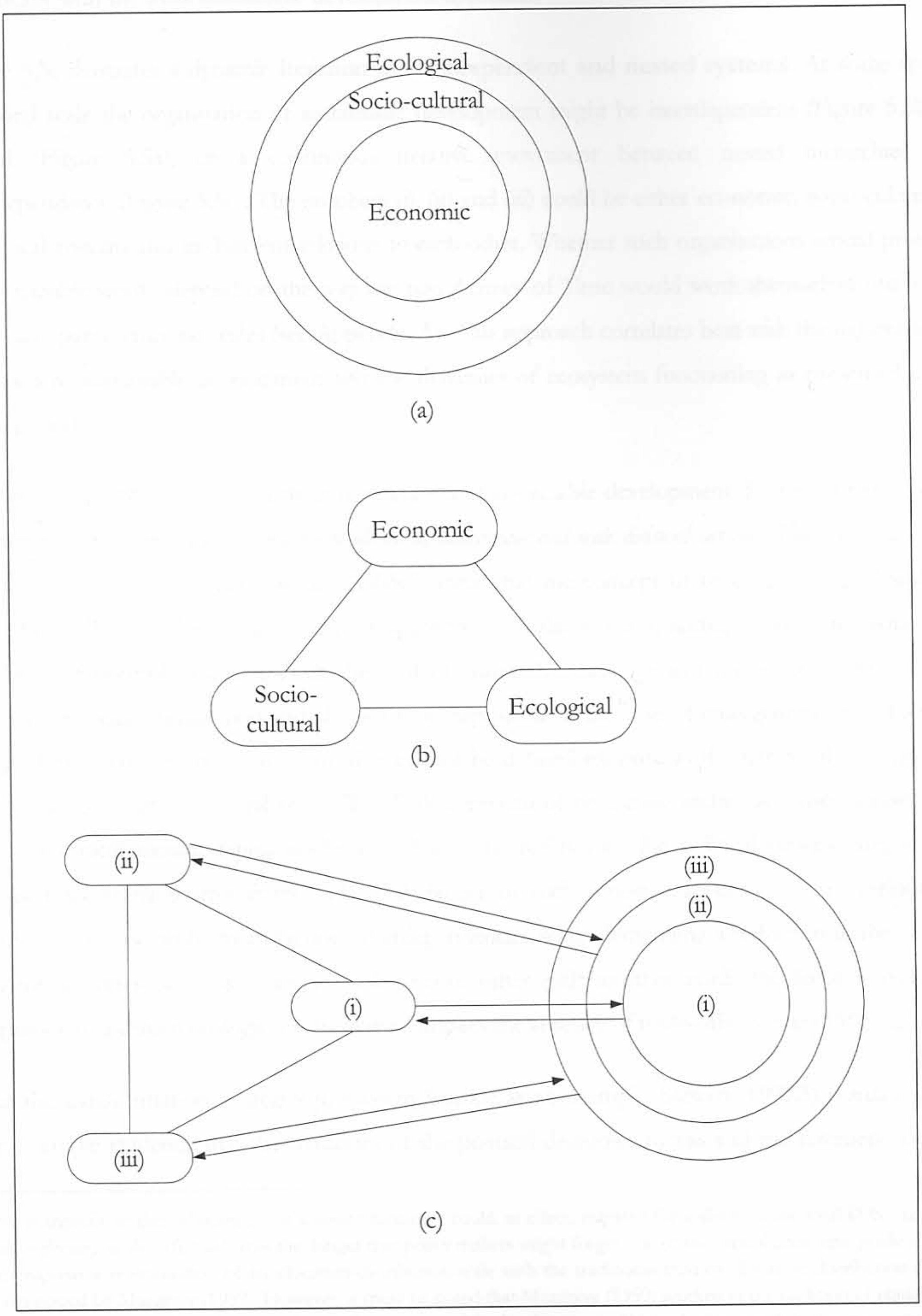
[34] Hierarchical organisation is also common in systems other than ecological systems. Clark, Perez-Trejo & Allen (1995:54) and Clark & Juma (1987:34-36) argue that the organisation of the economic system in the vertical relationships between households and production, as introduced in most economic textbooks, is somewhat misleading. The macro-economic system is, in effect, a nested hierarchy, consisting of the subsystems sectors, industries, firms and divisions.

Figure 5.5 The organisation of a sustainable development system (SDS)



Source: Own analysis

Figure 5.5b illustrates the situation where the economic, ecological and socio-cultural systems are **interdependent**, but no system imposes constraints on any of the other systems. Köhn (1998:183) refers to this type of situation as a one-level hierarchy. In this situation trade-offs between these systems are possible under all circumstances. This organisation correlates best with the CTA and more specifically with the weak sustainable development approach.

Figure 5.5c illustrates a dynamic **iteration of interdependent and nested systems.** At some spatio-temporal scale the organisation of sustainable development might be interdependent (Figure 5.5b) or nested (Figure 5.5a), or a continuous iterative movement between nested hierarchies and interdependence (Figure 5.5c). The numbers (i), (ii) and (iii) could be either economic, socio-cultural or ecological systems and in different relations to each other. Whether such organisations would prove to be sustainable would depend on the way the two Arrows of Time would work themselves out within particular spatio-temporal scales (see Appendix A). This approach correlates best with the *(co)-evolutionary* approach to sustainable development and the dynamics of ecosystem functioning as presented in the Holling-model.

Stewen (1998, 1999) describes such an organisation of sustainable development. Stewen (1999:2) points out that in *everyday reality the three levels of allocative, distributive and scale decisions are mixed together in a political process.* Stewen (1998:120) and Duchin (1996:6) argue that the concept of binding ecological scale, as defined by Daly and others, does not create space for the realities of a dynamic, evolutionary world. The possibility of optimal design towards the goal of sustainable development (as measured in terms of adherence to scale, distribution and allocation) is impossible in the case of emergent novelty (Faber & Proops 1990). The organisation of an SDS cannot be defined **ex ante** as the nature of the system is different across spatio-temporal scales. The Daly-approach of nested-hierarchies is a special case when particular critical natural capital is threatened and the realities of the political process are, in fact, organised according to this framework. The danger of such a nested approach is to overlook the complexities of the problem and ignore interdependencies while demanding a reduction in the scale of economic activities. Scale issues are not isolated from other goals, in other words: the decision to enforce compliance to a certain ecological scale in itself implies the absence of trade-offs (Stewen 1998:122)[35].

Using the transformation strategies in Eastern Europe as an example, Stewen (1999:3) points out that there is ample evidence that the dynamics of the political decision process and the interdependencies

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[35] Stewen argues that the enforcement of a nested hierarchy could, in effect, threaten the stability of the total SDS. He argues that neglecting trade-offs reinforces the danger that policy makers might forget one of the central economic goals: stability. He proposes a re-integration of an allocation-distribution-scale with the traditional triad of allocation-distribution-stability as developed by Musgrave (1959). However, it must be noted that Musgrave (1959) worked in the tradition of equilibrium-minded economists, who adhere to the CTA to sustainable development. Although the search for some criteria that represent the behaviour of a complex system is acknowledged, stability cannot be accepted as only criterion in the light of the discussion on stability, resilience and complexity. The emphasis on resilience and stability rather than stability alone appears to be more appropriate when the Holling-model is taken into account. The economic value of a system depends on its ability to maintain the flow of goods and services for which it is valued (Perrings 1998:506). The capacity to provide these services depends on the overall resilience of these systems. Although not more than a research agenda at this stage, ecological concepts and tools can help in a broader approach to economic-environmental systems (Perrings 1998:518). The linkages between the inconclusive ecological debate on Holling dynamics and the SDS cannot be made satisfactorily at this stage. This is an area highlighted for further research.

between social goals were underestimated. **Gradual strategies** that take account of socio-cultural, economic and ecological feedback effects are more adequate, both for the Eastern European case for the transition from socialism and for ecological structural change.

The important point in this discussion for the purpose of framing economic policy in case of complex and dynamic environmental problems, is that sustainable development policies should be evaluated on a case-by-case basis. The SDS can be organised in different ways, depending on the case at hand. In the cases where critical capital is at risk, the nested approach is applicable and in the case where trade-offs are needed the co-evolutionary approach is more suitable. The nature of complexities at allocation, distribution and scale are important in determining the organisation of the SDS. In the real world the broad framework wherein such decisions are carried out, are framed on the political level.

5.4 CONCLUSIONS

In this chapter it was argued that the concept of sustainable development could be interpreted as a complex, dynamic system. The economic, ecological and socio-cultural systems are components in this sustainable development system (SDS). The character of systems in general was introduced, providing a means to describe the behaviour of the components of the SDS and the way it could be organised. The behaviour of ecosystems, for example, is not well understood, and the focus is on a case-by-case approach to systems behaviour. The type of complexity is important in evaluating system behaviour. The organisation of the SDS is not hierarchical in all cases. The nature of allocation, distribution and scale are important parameters in determining the organisation of the SDS under observation.

The organisation of the SDS is incomplete without referring to dynamic change and the realities of the political process. The capital theory approaches, with the emphasis on the optimisation of a measured goal of sustainable development – whether strong or weak interpretations of sustainable development – do not account for processional realities of environmental problems. In the case of novelty in either ecological or innovative systems, a gradual approach to policy making is more appropriate, but only if feedback processes are well-structured. In the next chapter the contributions from public policy approaches to steer complexity and dynamic change are introduced.