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# A systems approach to sustainability and sustainable development

Gilberto Gallopín

NACIONES UNIDAS

CEPAL
ECLAC

Sustainable Development and
Human Settlements Division

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# Abstract

The concepts of sustainability and sustainable development are analyzed from a systems perspective. In the most general terms, sustainability of any system can be represented by a non-decreasing valuation function of the outputs of interest of the system considered.

Different perspectives on the system of reference are discussed, from the extreme anthropocentric to the extreme bio- or ecocentric positions, and related to the criteria (based on the assumed substitutability between natural and manufactured capital) of very strong, strong, weak, and very weak sustainability.

A set of underlying determinants of sustainability is proposed and discussed, including availability of resources, adaptability/ flexibility, homeostasis, capacity of response, self-reliance, and empowerment.

The concept of sustainable development is discussed and alternative theoretical perspectives that have been used in the literature are presented.

The relationship between sustainability, development, non-development, and maldevelopment; and material and non-material economic growth is mapped as a Venn diagram; alternative trajectories towards sustainable development for rich and poor countries are identified.

Five alternative paradigms/strategies for sustainable development are summarized, showing the complexity of the process of choosing the right actions to move towards sustainable development.

# I. Introduction

The concept of sustainability and particularly of sustainable development figure among the most ambiguous and controversial in the literature. The present document is an attempt to examine these concepts from a systems perspective, seeking to abstract their fundamental elements.

It is becoming increasingly clear that the quest for sustainability and sustainable development requires integrating economic, social, cultural, political, and ecological factors (UNCED 1992, Gallopín et al. 2001, Kates et al. 2001). It requires the constructive articulation of the top-down approaches to development with the bottom-up or grassroots initiatives. It requires the simultaneous consideration of the local and the global dimensions and of the way they interact. And it requires broadening the spatial and temporal horizons to accommodate the need for intra-generational as well as inter-generational equity.

In dealing with these issues, the systems approach can offer a perspective more useful than other analytical approaches, because the systems view is a way of thinking in terms of connectedness, relationships, and context.

Section II proposes a general definition of sustainability applicable to any open system, and distinguishing between sustainability of the outputs of the system and of the system itself. Section III addresses the important ideological differences associated with the choice of the system of reference in the discussions of sustainability, and the related economic concepts of weak and strong sustainability.

A set of fundamental whole-system attributes underlying system sustainability is proposed in section IV. Section V introduces the concept of sustainable development and reviews the different theoretical perspectives from which it has been approached. In Section VI a discussion of different development situations is presented, distinguishing between development, underdevelopment, and maldevelopment in terms of their sustainability, desirability, and between the situation of rich and poor countries. Section VII discusses five alternative paradigms of sustainable development, which illuminate differences in goals and worldviews of strategic significance.

Finally, Section VIII presents a number of conclusions derived from the analysis performed.

# II. A basic notion of sustainability

The concept of sustainability is a complex one; however, it is possible to distil some of its most basic and general characteristics by adopting a systemic approach.

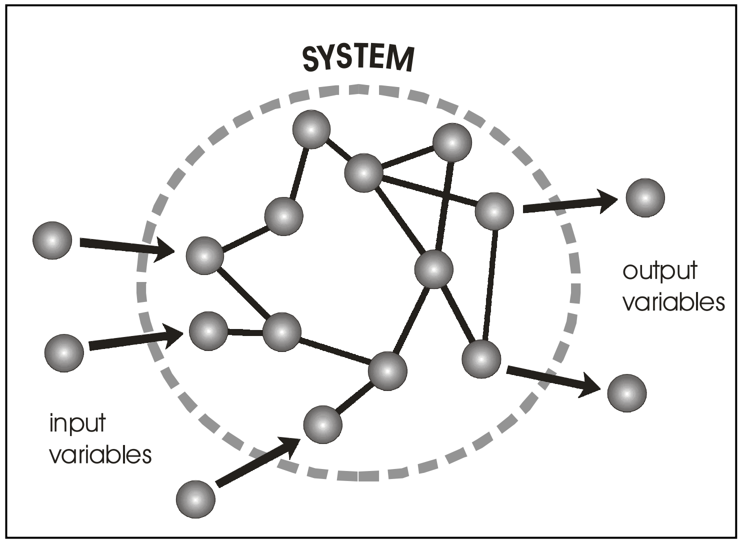
For the present purposes, a system is simply defined as a set of interrelated elements (or subsystems). The elements can be molecules, organisms, machines or their parts, social entities, or even abstract concepts. The relations, interlinkages, or "couplings"[1] between the elements may also have very different manifestations (economic transactions, flows of matter or energy, causal linkages, control pathways, etc.).

All physically existent systems are *open*, having exchanges of energy, matter and information with their environment that are significant for their functioning.[2] Therefore, what the system "does", its behavior, depends not only on the system itself, but also on the factors, elements or variables coming from the environment of the system and impinging on it (the "input variables"); on the other hand, the system generates variables that exert on the environment (the "output variables") as illustrated in Figure 1.

1 In abstract terms, the elements and the relation between the elements defines a system. The term "relation" is used here broadly to include also similar terms such as "constraint", "structure", "organization", "cohesion", "interaction", "interconnection", "correlation", "pattern".

2 Systems open to energy but closed to exchanges of matter are sometimes called *isolated*, but this distinction is not fundamental here.

**Figure 1**
**AN OPEN SYSTEM; THE STATE VARIABLES ARE THOSE INTERNAL TO THE SYSTEM**




**Source:** Author's elaboration.

Thus, the state of the system (the set of values adopted by all the internal variables of the system)[3] at a given time, is determined by the previous state of the system and by the inputs received by the system in the last period of time[4].

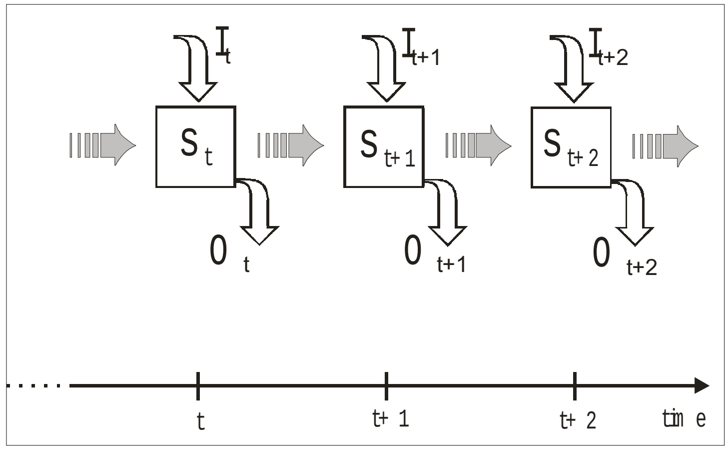
This can be represented (Gallopín, 1996), for notational simplicity (the same reasoning applies for continuous systems), by the canonical definition of a finite-state general system (Gill 1969):

$$S_{t+1} = \mathcal{F}(S_t, I_t)$$
$$O_{t+1} = \mathcal{G}(S_t, I_t)$$

Where **S** denotes the internal state of the system, **I** is the input vector (the list of all input variables) to the system, **O** is the output vector from the system, and **F** and **G** are functions (deterministic or probabilistic). The subindex **t** stands for time. The output variables are those considered of interest for the performance of the system; some (or all) of them may be state variables. In the general case, all the variables may vary over time, space and "population".[5] The pair of equations above defines the behavior of the system. See Figure 2 for a graphical representation.

[3] In its most general definition, a state is "any well-defined condition that can be recognized if it occurs again" (Ashby, 1956).
[4] In general, the memory of past changes is imbedded in the current value of the state, and therefore this generic formulation also applies to systems with time-lags.
[5] Any meaningful grouping, such as Company, type, country, or income bracket.

**Figure 2**
**STATE TRANSITIONS OF A FINITE-STATE SYSTEM**




**Source:** Author's elaboration.

Using this framework, sustainability can be defined in elementary terms[6] by:

$$\boxed{V(O_{t+1}) \geq V(O_t)}$$

Where **V** is a valuation function of the outputs of the system (i.e., a sustainable system is a system for which the net "worth" –not necessarily in economic terms– of the output produced is non-decreasing in time). Any valuation implies a strong subjective component, and therefore the specification of the function **V** (and the choice of output variables of interest) may vary widely reflecting the range of perceptions and positions regarding the relationships between nature and society (some of those views are discussed in the next section). For some, **O** is simply the total capital stock, and **V** is a monetary measure of that stock. Others may define **V** as some kind of aggregate welfare function, and **O** may be differentiated between natural, manufactured, and social capital. Or **V** could be a valuation function including some ethical priorities for the conservation of all living species, expressed in non-monetary units. It is precisely in the explicit or implicit constructive specification of the function and its arguments where many of the discrepancies about the meaning of sustainability and sustainable development become manifest.

Sometimes we are interested in the *sustainability of the system itself* (e.g., the preservation of a natural ecosystem such as a pristine forest); in this case, the output variables are the same as the state variables (in other words, what is sought is the preservation of the system itself). When the output variables are different from the state variables, we are referring to the *sustainability of the output(s) of the system* (e.g. agricultural yield of an agroecosystem[7]), not necessarily to the sustainability of the system.

When referring to the sustainability of a system it should be made clear which sustainability is being considered, because the implications may be quite different for each case. Sometimes, we want to sustain part of the output but change the system.[8] Sustainable development implies change; sometimes we want to improve or transform the system, sometimes we want to change the system to improve some of its outputs.

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6 More sophisticated definitions are possible, such as using the integral of the outputs through time.
7 This can be related to the concept of "non decreasing production (or consumption) stream or flow" used by economists.
8 For example, when the intent is to move from a military dictatorship to a democratic system while simultaneously maintaining the manufacturing sector developed under the military dictatorship.

# III. The subject of sustainability

The preceding discussion helps to clarify some of the underlying differences in the debates on sustainability and sustainable development. Those who will only pay attention to the sustainability of the social, or socio-economic system,[9] and those who will privilege only the sustainability of Nature represent the poles. The alternative views can be characterized, in a simplified way, as follows:

**Sustainability of the human system** only. This position, if taken to the extreme, could result in the Earth becoming a totally artificialized planet if total substitutability of natural resources and services were possible. The classical economicist view, for instance, regards the economy as the relevant system, and relegates nature to the role of provider of natural resources and services and of a sink for the wastes produced by human activities (Figure 3). This is consistent with the notion of "very weak sustainability"[10] (Turner 1993). The very weak sustainability approach asserts that natural and manufactured capital can substitute perfectly for one another. The substitutability of different types of capital implies that the preservation of an aggregate level of natural plus manufactured capital, rather than the preservation of natural capital in particular, is crucial.[11] The sustainability of ecological systems is viewed as important only as far as required for the sustainability of the human component. But there is too much we do not know (in this situation

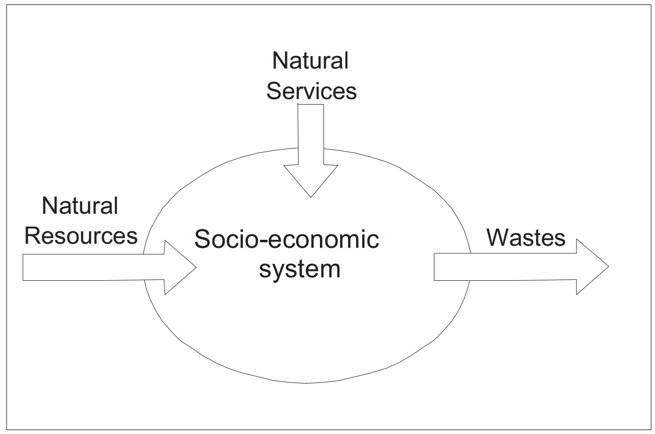
[9] Note that the term "socio" includes all that is human (economic, social, demographic, cultural, etc.).

[10] Pearce and Atkinson (1992) coined the concepts of weak and strong sustainability. Turner (1993) further subdivided them into very weak, weak, strong and very strong categories.

[11] It includes the so-called "Hartwick-Solow sustainability" which requires maintenance of the total capital stock (natural and human-made) of society, and "Hicksian sustainability" which requires non-decreasing comsumption-including consumption of environmental goods and services (Ayres et al. 1998).

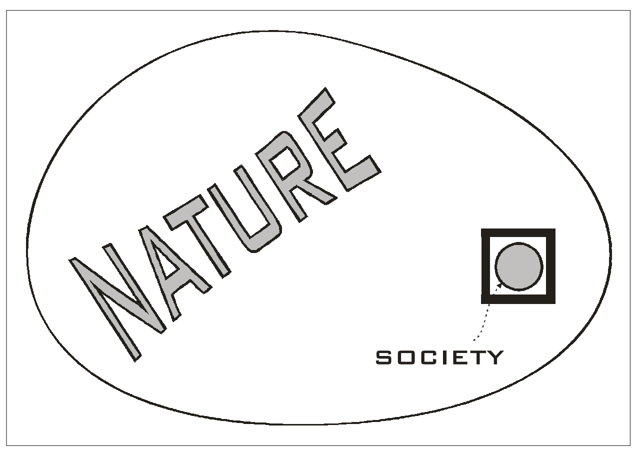
the *precautionary principle*[12] is called for). Precautionary approaches are necessary in order to incorporate an appropriate level of risk aversion in the face of uncertainty. There is also the issue of desirability or preferences: would we like to live in an artificial planet?.

**Figure 3**
**THE EXTREME ANTHROPOCENTRIC POSITION**




**Source:** Author's elaboration.

**Figure 4**
**THE EXTREME BIOCENTRIC POSITION**




**Source:** Author's elaboration.

**Sustainability of the ecological system** primarily, even if it means elimination or displacement of the human component (Figure 4). Those who would value ecological sustainability above and beyond, rather than equal or subordinate to, economic and social sustainability represent an extreme "deep green" position in opposition to the anthropocentric one. This perspective is consistent with the concept of "very strong sustainability". The very strong sustainability position asserts that natural resources cannot be substituted by human-made capital; they cannot be

[12] Defined by the United Nations Rio Declaration on Environment and Development, 1992, in the following way: 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.'

depleted, therefore, without an irreversible loss in social welfare. Very strong sustainability favors a more fundamentalist mode of ecological solidarity with the Earth and all forms of life. This view is most compatible with a steady-state economy. Here, the preservation of the environment –a biocentric viewpoint– is the ethical precondition for sustainability. Pursuing ecological sustainability by way of diminishing social and economic concerns, even to the point of excluding humans or increasing human poverty, is not acceptable for the majority of us.[13]

**Figure 5**
**A SOCIO-ECOLOGICAL SYSTEM**

**Source:** Modified from Castri (1981).

**Sustainability of the whole socio–ecological system**. The only option that makes sense in the long-term is to seek the sustainability of the whole socio–ecological system. The rationale for considering the whole system is based upon the existence of important interlinkages between society and nature. A s*ocio–ecological system* (Gallopín *et al*., 1989) is defined as any system composed of a societal (or human) component (subsystem) in interaction with an ecological (or biophysical) component. It can be either urban or rural, and it may be defined at different scales from local to global.[14] (See Figure 5 for an allegoric representation; Figures 6 and 7 are alternative systemic representations). This outlook is consistent with the notion of "strong sustainability". The strong sustainability approach holds that different types of capital are not necessarily substitutable, so that minimum amounts of a number of different types of capital (economic, ecological, social) should be independently maintained, in real physical/biological terms. The major motivation for this insistence is derived from the recognition that natural resources are essential inputs for economic production, consumption or welfare that cannot be substituted for by physical or human capital. It is understood that some environmental components are unique and that some

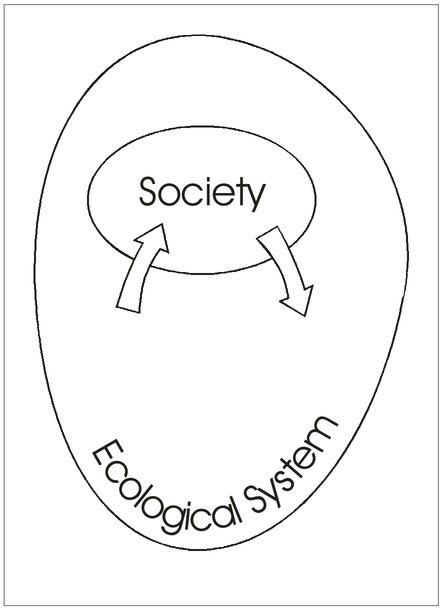
13 There are those who would hold that this position could be well-justified in some very specific, localized situations such as keeping people out of national parks; there is room for debate on this issue.

14 Local may be a household and its interactions with its immediate surroundings, and global is understood as the whole of humankind and its interactions with the natural world or biosphere.

environmental processes may be irreversible (over relevant time horizons). Therefore, strong sustainability implies that the aggregate amount of natural capital has to be maintained essentially at the present level. Under this notion, any development path that leads to an overall reduction of the stocks of natural capital (or, specially, to a decline below the minimum) fails to be sustainable even if other forms of capital increase.[15]

**Figure 6**

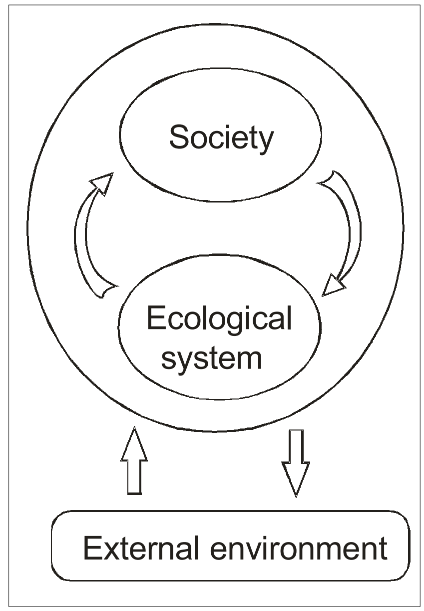
**A SOCIO-ECOLOGICAL SYSTEM REPRESENTATION EMPHASIZING INCLUSION RELATIONS**




**Source:** Author's elaboration.

**Figure 7**

**A SOCIO-ECOLOGICAL SYSTEM (LARGE OVAL) REPRESENTATION EMPHASIZING FUNCTIONAL RELATIONS, INTERNAL AND WITH THE EXTERNAL WORLD**




**Source:** Author's elaboration.

The sustainability of the whole socio-ecological system may also be compatible with the notion of "weak sustainability". Weak sustainability places emphasis on the value of safeguarding ecological and biogeochemical processes that are irrecoverable if lost. These processes and their associated species mix are referred to as *critical natural capital*. Critical natural capital should not be allowed to be substituted for, but otherwise manufactured capital of equal value can take the place of natural capital.[16] One major problem lies in the choice of criteria for assigning value to the ecological assets, considering the arguments about the incommensurability[17] of ecological and manufactured capital.

15 Sustainability here is viewed as non-diminishing life opportunities (Ayres et al. 1998).
16 A society is said to be weakly sustainable if well-being is non-declining from generation to generation.
17 Incapable of being measured against a common standard.

# IV. Looking for fundamental attributes underlying sustainability at the level of whole socio-ecological systems

What is required for a socio-ecological system to be sustainable? Different attributes may be identified, depending on the specific socio-ecological system and particular component (soil, vegetation, social group, etc.) considered. However, it seems reasonable that some generic systemic properties would be universally required for the sustainability of socio-ecological systems. A proposal for such a set of basic, total-system attributes has been made by Gallopín (1994). Some of these properties arise from the ecological and human subsystems, and others only from the human subsystem, but all are important at the whole socio-ecological system level. Those basic properties are:

- **Availability of Resources.** This is an obvious attribute, and it can include *resources* (e.g. water, light, money, etc.) *assets* and *entitlements*.
- **Adaptability and Flexibility (as opposed to Rigidity).** A degree of plasticity[18] is required to detect and make sense of changes occurring in the outside world. If that capacity is lost, the system may become rigid and unable to detect changes. As the environment keeps changing undetected by the system, or detected

[18] Plasticity being understood as the capacity of the whole socio-ecological system to be influenced and modified by its environment.

but without the system adapting to the new conditions, the system will eventually collapse, because its behavior will no longer be compatible with the new situation.

- **General Homeostasis: Stability, Resilience, Robustness (as opposed to Vulnerability, Fragility).** This refers to the capacity of the system to maintain or preserve the values of essential variables around (near) a given trajectory or state (stability), a given domain of attraction (resilience), or a given system structure (robustness).

This capacity can erode slowly in a manner difficult to perceive. There are many examples in natural resources management in which this has happened, leading to loss of homeostasis at different levels. Exemplifying this, the rapid expansion of the cholera epidemics in Latin America in 1994 can be connected with the slow erosion of basic sanitation services during the 80's (the "lost decade" for the region). An important point (Nicolis and Prigogine 1977, Prigogine and Stengers 1979) is that the new structure arising from structural change is inherently unpredictable.

- **Capacity of Response.** This refers to the capacity of a socio-ecological system to cope with change.

Capacity of response is in some way related to the capacity to maintain or enlarge the system's repertoire of options. It is also related to the "ability to switch strategies according to condition".

Capacity of response is built upon adaptability, homeostasis and awareness.

- Self-reliance (as opposed to Dependency).[19] Self-reliance refers to the capacity of a socio-ecological system to regulate its interactions with its environment. Such a capacity depends upon the degree to which the system exercises control over its own interactions with its environment.

- Empowerment. This attribute denotes the capacity of the socio-ecological system not just to respond to change, but to innovate and induce change in other systems in pursuit of its own goals. It should be noted that this attribute can apply specifically to the human subsystem, but not to the ecological subsystem.[20]

The above set of attributes represents a preliminary proposal, pointing to the need to think about basic underlying attributes for sustainability, rather than about attributes or properties of parts or components.

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[19] Self-reliance should not be confused with self-sufficiency nor with autarky.

[20] In some sense, the process of natural evolution often led to species influencing other species (i.e. competition or mutualism) but this non-conscious "empowerment" unfolds at time scales much slower than the human actions considered here.

# V. Sustainable development[21]

Sustainability is not the same as constancy. Although sometimes sustainability is presented as meaning the maintenance of a fixed state of a system, this is not scientifically correct; even pristine ecosystems are in permanent change, involving renewal and destruction of components, adapting to changes in their environment and coevolving with it. There are many examples involving fisheries, managed forests and wildlife, and other forms of management of ecological resources that have shown that attempts to “freeze” the variables of the system in attempts to obtain “optimal performance” often lead to loss of resilience of the system and even its collapse (Holling, 1973, 1986).

All living systems are changing systems and the essential point is not to eliminate change, but to avoid the destruction of the sources of renewal,[22] from which the system can recover from the unavoidable stresses and disturbances to which it is exposed because of its condition of being an open system.

The concept of *sustainable development* is quite different from that of *sustainability*[23] in that the word “development” clearly points to the idea of change, of directional and progressive change. As will be discussed later, development does not necessarily mean quantitative growth, being more akin to the notion of qualitative unfolding of potentialities and increasing complexity (which, depending on the concrete situation, may or may not include or require quantitative growth).

[21] From Gallopín and Christianson (2000).

[22] The sources of renewal are often system-specific; for instance, the renewal of moist tropical forests depends critically on the maintenance of the understory, and the sources of renewal of many societal systems lay in the social and natural capital.

[23] Which can be applied to the maintenance of an existing situation or system state.

Here, what is sustained, or has to be made sustainable, is the process of improvement of the human condition (or better, of the socio-ecological system to which humans pertain), a process that does not necessarily require indefinite growth in the consumption of energy and materials.

We are living through a period of tremendous demographic, technological, and economic transformation. In an attempt to ensure that the changes affecting humanity are changes for the better, the world community has initiated the process of redefining progress. This attempt at redefining progress is known as sustainable development.

The speed and magnitude of global change, the increasing connectedness of social and natural systems, and the growing complexity of societies and of their impacts upon the biosphere, highlight that sustainable development must aim not only to preserve and maintain the ecological base for development and habitability, but also to increase the social and ecological capacity to cope with change, and the ability to retain and enlarge the available options to face a natural and social world in permanent transformation.

Thus, the concept of sustainable development cannot mean merely perpetuation of the existing situation. The central question is what is to be sustained, and what is to be changed. Moving towards sustainable development requires:

- Removing accumulated rigidities and impediments;
- Identifying and protecting the accumulated foundations of knowledge and experience that are important as a basis upon which to build;
- Sustaining the social and natural foundations for adaptation and renewal, and identifying and enhancing the lost renewal capacity needed;
- Stimulating innovation, experimentation and social creativity.

The body of literature pertaining to the topic of sustainable development is both voluminous and dissonant. The multitude of opinions on sustainable development may be indicative of the high-stakes involved. Indeed, trying to formulate a new framework for human reasoning capable of underlying the arrangements of our evolving society is of significant concern.

Amid the diversity of approaches to sustainable development there are, of course, some recurrent elements that provide some degree of internal consistency to the body of literature. The aim of this section is to review basic elements of the sustainable development concept.

## a) The ethical foundations of sustainable development

Opinions about what constitutes the ethical foundation of sustainable development vary to some degree. One ethical concern that is often referred to in the sustainable development literature is that of intergenerational justice[24] (Costanza, 1991, Vercelli, 1998). This concern is explicitly mentioned in the general definition of sustainable development prepared by the World Commission on Environment and Development (see the following concept subsection for definition).

Notably, the idea that future generations should be compensated for reductions in the endowments of resources brought about by the actions of present generations is sometimes in tension with another often cited ethical basis for sustainable development –intragenerational equity–. Intragenerational equity is concerned with the reduction of resource disparities among those presently living today.

Another ethical concern, that complements the anthropocentric objectives of intergenerational and intragenerational justice, is the ecocentric concern for biodiversity,

[24] Closely related to the “equitization”paradigm of sustainable development (see Section VI).

sometimes referred to as Biophilia (Wilson, 1986) and already visited in Section III. Biophilia represents an appreciation of the intrinsic values in nature. The ecocentric objective of Biophilia is to preserve diversity, from species to ecosystems (Bergh and Jeroen, 1996). Variations on Biophilia have been put forth by the Deep Ecology school of thought (Drengson and Inoue, 1995).

## b) Dynamism

Sustainable development cannot exist as some static equilibrium state that can be regulated by reference to constant limits and some simple notion of balance between the various dimensions (Brooks, 1992). Permanent technological innovation and changes in social organization make sustainable development to be a dynamic process. Rates of change are important determinants of sustainable development (Froger and Zyla, 1998). A dedication to learning how rates of change affect the behavior of social, ecological and economic systems over time is an important part of the process of enabling sustainable development.

## c) Concept

Since its introduction in the late 1970s the concept of sustainable development has suggested a synthesis between economic development and environmental preservation (Bergh and Jeroen, 1996*)*. The need for this type of synthesis derives in large part from the fact that permanently decreasing environmental stocks cannot support increasing or perhaps even constant levels of material economic throughputs for an indefinite period of time (Drummond and Marsden, 1999*)*.

Definitions of sustainable development hold in common a respect for the need to integrate economic and environmental concerns. Beyond this basic consideration, commonalties among definitions of sustainable development are more subtle.

The most often cited definition of sustainable development is the one proposed by the United Nations Commission on Environment and Development (otherwise known as the Brundtland Commission) in 1987 (WCED 1987). In its report to the United Nations General Assembly, entitled Our Common Future, the Commission defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

Many attempts to promote sustainable development involve strategies designed to define and subsequently monitor some form of “sustainability limits” (Farrell and Hart, 1998). This approach is premised upon the observation that natural resources are finite and that there are limits to the carrying capacity of the Earth’s ecosystems.

Another approach to sustainable development, which is often linked in some manner with the sustainability limits approach, is the “competing objectives” approach, which focuses on reconciling social, economic and ecological goals (Peterson, 1997*)*.

To generalize, approaches to sustainable development from an ecological perspective stress the importance of focusing on the societal ability to resist or recover from disturbances, stresses and shocks rather than on its ability to produce goods (Vercelli, 1998). Alternatively, approaches to sustainable development from an economic perspective define economic development (sometimes assumed to be synonymous with economic growth) as sustainable whenever a certain crucial variable may be ‘sustained’, in the sense that it is not bound to diminish in the future as a consequence of growth itself. In the literature, approaches to sustainable development may be grouped into three sets according to whether the crucial variable or objective function to be maximized is welfare (or utility), consumption, or (man-made and/or natural) capital. The choice of the crucial variable has far-reaching implications since its sustainability often implies the unsustainability of other plausible candidates for this role (Vercelli, 1998*)*. The later author departed from those categorizations by proposing that the freedom of future generations should be taken as the basic variable to be preserved through time by economic development.

## d) Implementation

If sustainable development is to be achieved, understanding the interlinkages between social, ecological and economic dimensions of our world is of significant importance. This is so because the behavior of a system is in general determined as much by the causal interlinkages between its variables than by the changes in the values of the variables themselves. To understand such interlinkages, it is worthwhile to adopt a systems approach to observing worldly phenomenon. A key feature of the systems approach is the recognition that outcomes are not necessarily predictable since our activities may ‘force’ a system into a whole new form of behavior (that could include collapse) never seen before (Holling, 1973, 1986; Gunderson *et al*., 1995, IGBP 2001).

Complementary to the need for a systems approach is the need to integrate multiple perspectives into the process of implementing sustainable development. A noteworthy point regarding sustainable development, a point that differentiates the concept from narrower ideas such as environmentalism, is that the concept is more than the sum of its parts (Brooks, 1992*)*.

A means of assessing progress towards sustainable development is integral to implementing the concept. Traditional market indicators are unable to signal whether or not the integrity of a natural system is being dangerously eroded. Thus these indicators need to be complemented by sustainability indicators. Some sustainability indicators that have been proposed refer to: reducing the impact that human activities have on the environment (particularly the rates at which renewable and nonrenewable resources are used); not exceeding the carrying capacity of natural resources and ecosystems; integrating long-term economic, social and environmental goals, and preserving biological, cultural and economic diversity (Bergh and Jeroen, 1996*)*.

Sustainability indicators must ultimately be linked with achievable goals. Setting goals for sustainable development amid large groups of stakeholders is a most difficult process. With large groups of stakeholders, diversity of value perspectives, derived from different life experiences and cultural histories, tends to undermine the possibility of any consensus on the criteria for sustainable development (Peterson, 1997*)*. This is particularly relevant to the global scale. To achieve global sustainable development, in light of this constraint, it may be best to allow for different regions to characterize sustainable development according to their specific interests and situation. A multi-region approach to global sustainable development would be based on the sustainable provision of natural resources and the sustainable import and export of resources, goods, services and waste (Redclift, 1994*)*.

A multi-region approach to global sustainable development would entail the elaboration of multiple concrete manifestations of sustainable development, that is, each region would be able to craft a distinct take on the sustainable development *problématiqu*e. In order to give justice to the cultural, social, economic and ecological diversity of the world, multiple ways of interpreting sustainable development must be encouraged. Unfortunately, the powerful homogenization elements[25] inherent to the globalization process as currently unfolding conspire against those aspirations.

[25] Particularly regarding national and international economic policies and reduction in the regulatory role of the State.

## e) A variety of perspectives

Table I presents a summary of theoretical perspectives used to characterize sustainable development. It is important to recognize that sustainable development can be treated as both a model and a point of legitimation (Farrell and Hart, 1998*)*. Accordingly, the term sustainable development is often used for different purposes in scientific and political realms (Drummond and Marsden, 1999). In the final analysis, no single group has authority to define sustainable development. Consequently, the concept is wed to ambiguity. This ambiguous character exemplifies the inherent rationalism of sustainable development (Drummond and Marsden, 1999*)*.

**Table 1**
**THEORETICAL PERSPECTIVES ON SUSTAINABLE DEVELOPMENT**

| Theory | Characterization of sustainable development |
|---|---|
| Equilibrium-Neoclassical | Welfare non-decreasing (anthropocentric); sustainable growth based on technology and substitution; optimizing environmental externalities; maintaining the aggregate stock of natural and economic capital; individual objectives prevail over social goals; policy needed when individual objectives conflict; long-run policy based on market solutions. |
| Neo-Austrian-Temporal | Teleological sequence of conscious and goal-oriented adaptation; preventing irreversible patterns; maintaining organization level (negentropy) in economic system; optimizing dynamic processes of extraction, production, consumption, recycling and waste treatment. |
| Ecological-Evolutionary | Maintaining resilience of natural systems, allowing for fluctuation and cycles (regular destruction); learning from uncertainty in natural processes; no domination of food chains by humans; fostering genetic/biotic/ecosystem diversity; balanced nutrient flows in ecosystems. |
| Evolutionary-Technological | Maintaining co-evolutionary adaptive capacity in terms of knowledge and technology to react to uncertainties; fostering economic diversity of actors, sectors and technologies. |
| Physico-Economic | Restrictions on materials and energy flows in/out the economy; industrial metabolism based on materials – product chain policy: integrated waste treatment, abatement, recycling and product development. |
| Biophysical-Energy | A steady state with minimum materials and energy throughput; maintaining physical and biological stocks and biodiversity; transition to energy systems with minimum pollutive effects. |
| Systems-Ecological | Controlling direct and indirect human effects on ecosystems; balance between material inputs and outputs to human systems; minimum stress factors on ecosystems, both local and global. |
| Ecological Engineering | Integration of human benefits and environmental quality and functions by manipulation of ecosystems; design and improvement of engineering solutions on the boundary of economics, technology and ecosystems; utilizing resilience, self-organization, self-regulation and functions of natural systems for human purposes. |
| Human Ecology | Remain within the carrying capacity (logistic growth); limited scale of economy and population; consumption oriented toward basic needs; occupy a modest place within the ecosystem food web and biosphere; always consider multiplier effects of human actions, in space and time. |
| Socio-Biological | Maintain cultural and social system of interactions with ecosystems; respect for nature integrated in culture; survival of group important. |
| Historical-Institutional | Equal attention to interests of nature, sectors and future generations; integrating institutional arrangements for economic and environmental policy; creating institutional long-run support for nature's interests; holistic instead of partial solutions, based on a hierarchy of values. |
| Ethical-Utopian | New individual value systems (respect for nature and future generations, basic needs fulfillment) and new social objectives (steady state); balance attention for efficiency, distribution and scale; strive for small-scale activities and control of 'side effects' ('small is beautiful'); long-run policy based on changing values and encouraging citizen (altruistic) as opposed to individual (egoistic) behavior. |

**Source:** Bergh and Jeroen (1996).

# VI. The different guises of development[26]

Development is about increasing the quality of life of human beings,[27] and not necessarily about increased GNP (not even of "greened" GNP which accounts for depletion of ecological capital).

Hence development is not synonymous with economic growth; the latter is only (one of) the means to the former. Development, in the last instance, is about improvements in the quality of life.

Quality of life embodies the satisfaction of material and non-material human needs (resulting in the level of health reached) and the fulfillment of human desires and aspirations (resulting in the level of subjective satisfaction obtained). Human needs, desires and aspirations can be met through a variety of alternative material and non-material satisfiers (Maslow and Lowery, 1998, Gallopín and Öberg, 1992; Mallmann, 1980).

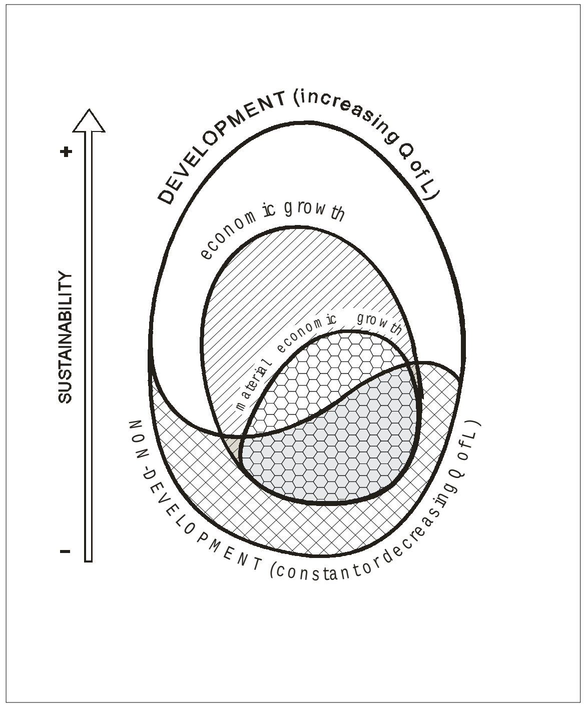
Contrary to common perception, economic growth is not necessarily synonymous with material growth. Material economic growth is now confronting both *source limitations* (scarcity of natural resources) and *sink limitations* (saturation of the natural capacity for dilution and neutralization of pollutants and wastes). Non-material economic growth has been increasing in the recent past; this relative dematerialization of the economy is evident in the increasing share of the services sector in the GNP (although not all services are immaterial, many are much less material-intensive than the

[26] Gallopín (1996a), Gallopín and Christianson (2000).
[27] Or, in economic terms, maximizing aggregate human welfare.

agricultural and industrial sectors of the economy) and the higher energy and resource efficiency of the new and emerging knowledge–intensive technologies.

Figure 8 represents the basic relation between development, economic growth, and material economic growth in the form of a Venn diagram familiar in set theory. Sustainability, in principle, increases along the axis material economic growth –non-material economic growth– no economic growth.[28] The figure is useful for mapping possible combinations of economic growth and changes in the quality of life (Gallopín, 1996a).

**Figure 8**
**A SET-THEORETICAL REPRESENTATION OF DEVELOPMENT, SUSTAINABILITY, AND ECONOMIC GROWTH, AND QUALITY OF LIFE (QOFL)**




**Source:** Author's elaboration.

One could say that *underdevelopment* occurs when neither quality of life increases nor economic growth takes place, a situation that affected many Latin American countries during the eighties and continues to plague many countries today, mostly in the south.

The situation where there is material economic growth, but quality of life does not increase, can be defined as *maldevelopment*; it occurs both in the north and in the south.

The combination of non-development with non-material economic growth is rare. However, it could characterize the situation of some fiscal havens or countries with service-based economies whose populations, for the most part, are resigned to a stagnant quality of life.

The combination of increasing quality of life with material economic growth is what is usually viewed as *development*. It currently occurs mostly in the north, but also in some countries

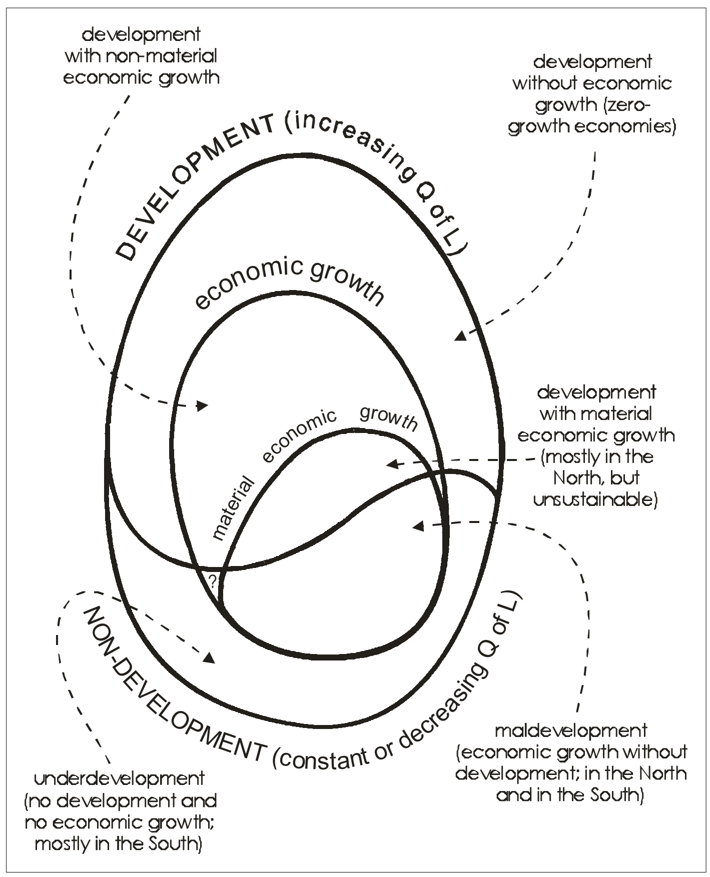
28 "No economic growth" can be consistent with development in the form of qualitative transformations.

in the south. However, in the long-term this situation is environmentally unsustainable, and in some instances (i.e., global climate change) critical environmental thresholds may have already been surpassed.

On our finite planet, even allowing for rapid technological change, a basic sustainable level of per capita material consumption will have to be reached. A reasonable way to do this will involve both increasing the material consumption of the billions of people living now in poverty and reducing material over-consumption by the rich minority.[29] Similarly, the global population will have to stabilize eventually.[30]

In the very long-term, there are two basic types of truly sustainable development situations: increasing quality of life with non-material economic growth (but no net material economic growth) and zero-growth economies (no economic growth at all). Sustainable development needs not imply the cessation of economic growth: a zero-growth material economy with a positively-growing non-material economy is the logical implication of sustainable development. While demographic growth and material economic growth must eventually stabilize, cultural, psychological and spiritual growth is not constrained by physical limits. Those situations are represented in Figure 9.

**Figure 9**
**THE DIFFERENT GUISES OF DEVELOPMENT**




**Source:** Author's elaboration.

29 Reducing material over-consumption by the rich minority can be achieved by reducing individual material consumption levels and/or by increasing the overall material and energetic efficiency of the economy.

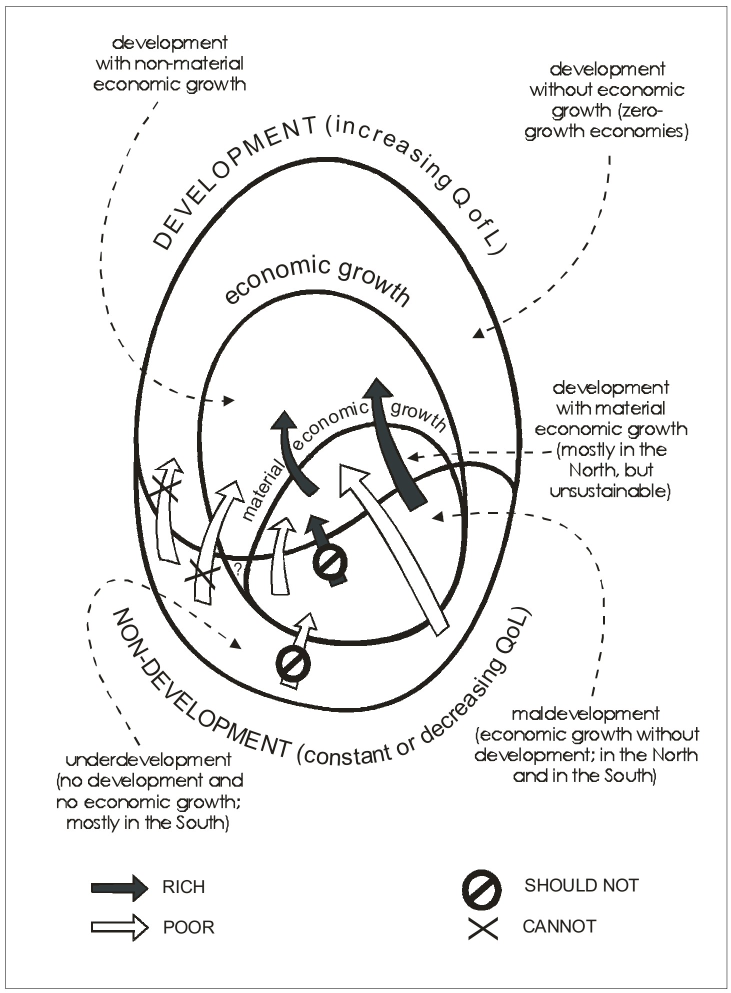
30 Global population stabilization can be achieved through improving peoples living conditions and their quality of life. Stabilization through imposition and violence, besides being ineffectual, is unlikely to be conducive to sustainable development.

Rich countries should attempt to move from maldevelopment or development with material economic growth, to development with non-material economic growth (or, if society so desires, the transition could be to a zero-growth economy).

Underdeveloped countries in most cases, however, will be unable to move from non-development to development without material economic-growth or to zero-growth economies, because of the fact that some level of accumulation and material economic activity is required to sustain development. The path from underdevelopment to maldevelopment is possible, but obviously inappropriate. Nevertheless, many countries continue to try and follow it.

After considering the alternatives, the only path realistically appropriate for developing countries, if sustainable development is to be achieved, is the one that goes from underdevelopment to development with material economic growth, and then to development without material economic growth. The paths discussed above, and the alternatives available in principle to rich and poor countries, are depicted in Figure 10.

**Figure 10**
**ALTERNATIVE DEVELOPMENT PATHS**




**Source:** Author's elaboration.

# VII. Alternative paradigms for sustainable development

Schellnhuber (1998, 1999) developed an interesting perspective for sustainable development using a cybernetic approach in the context of global environmental change. Rather than attempting to formulate a single and binding definition, he proposes a set of precise optional paradigms[31] of coevolution of the human and natural subsystems of the (global) socio-ecological system, emphasizing different fundamental motives of human actions. The following discussion is an attempt to generalize his approach to any scale from the local to the global and to any socio-ecological system.

The state of a socio-ecological system can be represented by a point in a multidimensional "state space" defined by all possible values of the set of variables that define the ecological (or "natural") subsystem and the human subsystem. As the system state changes through time, the succession of states defines a trajectory for the system in this abstract state space.

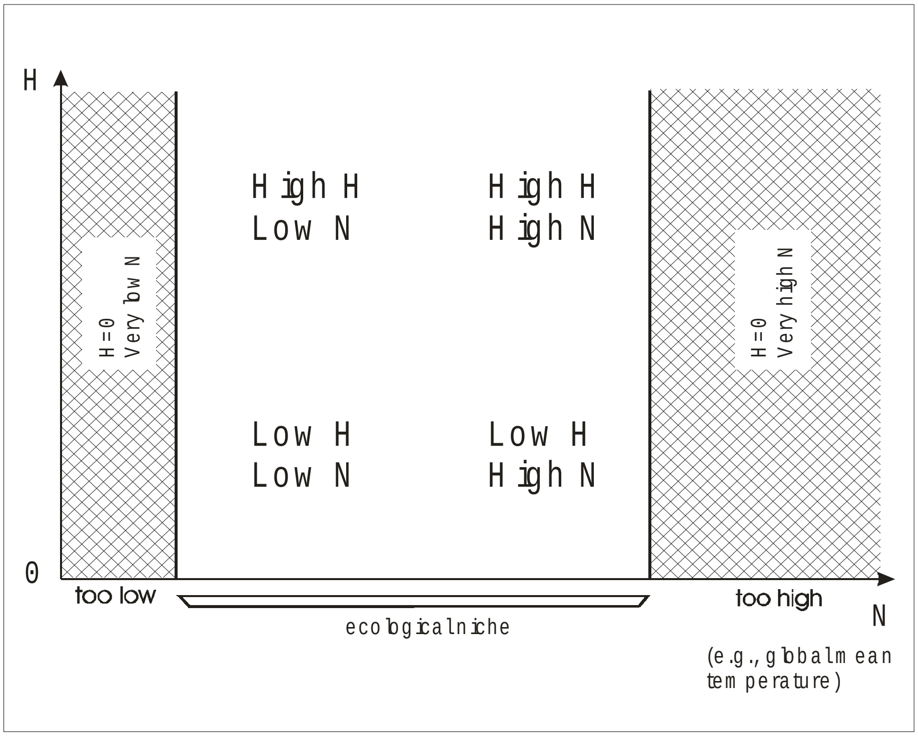
For simplicity, in what follows all the variables describing the ecological subsystem and all those describing the human subsystem will be condensed down to only two variables, N and H respectively. N represents the state of the natural subsystem (for instance global mean temperature, or a local aggregate index of environmental

[31] The term "paradigm" as used by Schellnhuber, seems to refer to a basic goal (such as optimization, stabilization, or other), a strategic direction, and the underlying assumptions about the functioning of the socio-ecological system.

conditions) and H represents the state of the human subsystem (e.g. the degree of development of human civilization, or the condition of the local human community).

Figure 11 shows the state space of the socio-ecological system. In this simplified example, the state space is the area defined by all possible values of the two variables N and H. There may be (depending of what are the specific variables represented by N) regions of the state space within which no life is possible (for instance, temperatures that are too cool or too hot to sustain human life). The values of N for which human life is possible constitute the ecological niche of humans.

**Figure 11**
**AN IDEALIZED REPRESENTATION OF THE STATE SPACE OF A SOCIO-ECOLOGICAL SYSTEM**

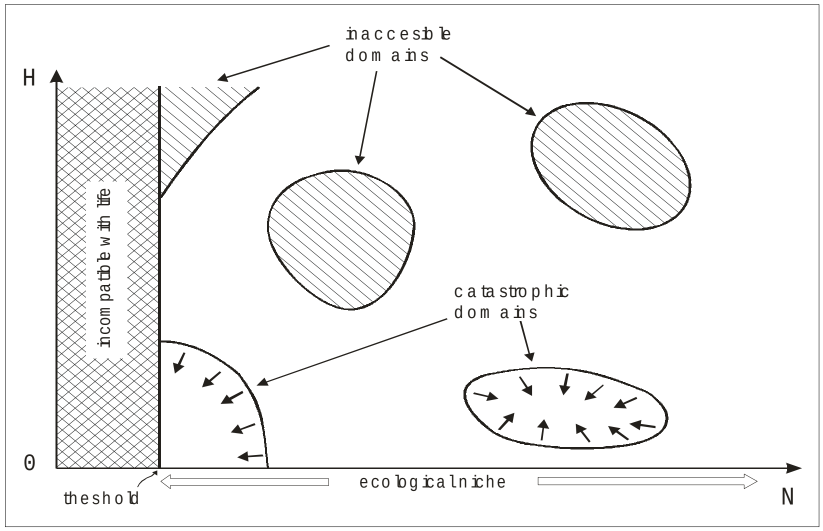



**Source:** Author's elaboration.

In the general case, the state space may contain "catastrophic domains", or regions where a) the quality of the socio-ecological system falls below a tolerable level, and b) once the state of the system enters the domain, it becomes trapped inside it. In the state space there may also exist 'inaccessible regions"; those are combinations of values of N and H that cannot be reached by any deliberate or spontaneous trajectory from the present or initial state $P_0$.

A generic state space for the coevolution of N and H will look like in Figure 12. Figure 13 illustrates some possible trajectories departing from the current state $P_0$.

**Figure 12**
**A GENERIC STATE SPACE FOR REPRESENTING THE COEVOLUTION OF N AND H**

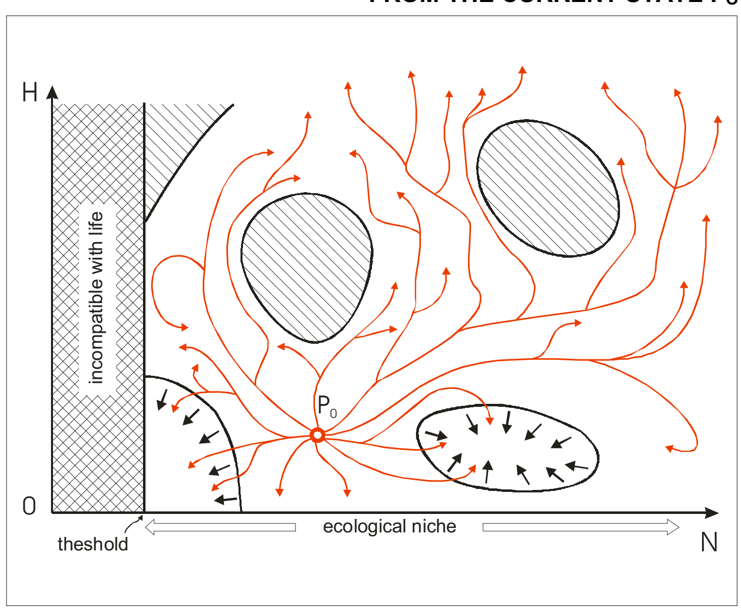



**Source:** Author's elaboration.

## a) Paradigm 1. Standardization

It implies the direct prescription of norms, values, development corridors, target domains, etc. for controlled coevolution of the N and H subsystems. In other words, it is based on the establishment of absolute environment and development standards, norms, quotas, or values to be reached. The coevolution criteria here are not strictly derived –or even derivable– from the internal dynamics of the socio-ecological system, but from essentially normative settings.

**Figure 13**
**STATE TRAJECTORIES ORIGINATING FROM THE CURRENT STATE $P_O$**




**Source:** Author's elaboration.

This paradigm offers a seductively simple possibility for operationalizing sustainable development: certain environmental and human variables(often chosen to be as simple as possible) or entire aggregate functions are declared "sustainability indicators", and the trajectory of the socio-ecological system is considered correct if the values of the indicators are maintained within the limits defined as the "safe range".

The utilization of this paradigm implies the assumption that the considered socio-ecological system is steerable more or less "by sight", i.e. via the largely statistical, perpetual evaluation of space and time close-range information.

The fundamental arbitrariness in the stipulation of coevolution norms in this paradigm involves the great danger that essential interactions, repercussions and side effects in the non-linear socio-ecological systems to be controlled or steered are not taken into consideration.

Schellnhuber (1998) goes on to show that some management strategies which satisfies all desired standards over the short term can lead nevertheless to an irreversible development which destroys the long-term feasibility of the paradigm (the possibility of a trajectory being contained within the safe range).

## b) Paradigm 2. Optimization

This implies a search for the "best", that is, maximizing an aggregated human-nature welfare function by choosing the optimal co-evolutionary trajectory over a fixed time period. Variations of this paradigm include the maximization of the mean utility over the long-term, or the acceptation of temporary drawbacks provided final utility is increased. Serious problems arise with this approach, including the analytical and political difficulties to define or impose target values for optimization. Another risk is that the success of the optimization paradigm rests on the assumption of perfect control over the socio-ecological system, but if that is not true, episodic departures from the ideal control scheme may result in the system falling in one of the catastrophic domains.

The optimization paradigm of sustainable development embodies an optimistic attitude that assumes that the best possible co-evolution can be actually realized under all circumstances. This requires rather perfect knowledge and a coherent volition process extending over many generations.

## c) Paradigm 3. Pessimization

This paradigm (see also Gallopín 1997) aims to avoid falling into the catastrophic domains; it is based on the precautionary principle of "preventing the worst", looking for the smallest possible amount of damage instead of the greatest possible benefit. This paradigm does not primarily determine the pessimal management sequence, but rather tries to exclude non-tolerable control options and therefore, a fairy large maneuvering space for management option usually remains.

## d) Paradigm 4. Equitization

This focuses on preserving the options for future generations; in other words, not contracting the "accessible universe" over time. "Equity" here is identified with equality of environment and development options for successive generations. To fulfill such a goal, a full analysis of all possible trajectories emanating from the present would be needed, and this is likely to be an impossible task, even in principle. Moreover, the dynamics of the socio-ecological system might not permit a trajectory fulfilling the preservation of *the same* options through time; the goal could then be to preserve *equivalent* options (accepting that some options could not be preserved but that new options will become possible).

The comparison of the options lost to the options gained to determine whether the overall opportunistic quality of the set of trajectories will be preserved is a most difficult task. Of course, it would be possible to introduce a short-term option criterion in the standardization paradigm for sustainable development on a short-term basis, but this will suffer from the same problems of that paradigm.

### e) Paradigm 5. Stabilization

This focuses on bringing the socio-ecological system into a desirable state in the co-evolution on state space and then maintaining it by good management. Note that the stabilization paradigm shifts the focus from "sustainable development" to "sustainability". The stabilization paradigm does not simply prescribe co-evolution states or paths, but searches systematically for balancing management options in accordance with the intrinsic dynamics of the socio-ecological system and the available repertoire of steering instruments. If the desired generalized equilibrium exists and is accessible, then criteria are needed for the choice of the trajectory leading to it (e.g. "soft-landing" or "crash-halt").

In the real world it is to be expected that, rather than pure paradigms, strategies trying to satisfy simultaneously a number of them would be implemented (e.g. complex paradigms representing a ranking or other combination of various pure paradigms).

The characterization of pure paradigms is nevertheless illuminating, not only because it highlights the fundamental dimensions involved, but also because it shows vividly that the challenge of choosing the "right actions" is not only normative (what society wants) but also ontological and epistemological (how and by which laws socio-ecological systems operate, and what do we know about them). This tri-layered complexification (volition, understanding, and socio-ecological dynamics) is typical of the problems of sustainable development (Gallopín et al., 2001).

# VIII. Conclusions

The major conclusions obtained from a systemic analysis of the concepts of sustainability and sustainable development are presented below.

When discussing sustainability, the clear specification of the system (or the outputs of the system) to which the concept is applied (What system? How defined? At what scale? Which outputs?) is essential to avoid confusion and ambiguity.

Many disagreements regarding the concrete meaning and implications of sustainability are associated to the use of different valuation criteria (or valuation function) utilized (i.e. relative weight allocated to natural and manufactured capital); therefore it is critical to clearly specify the criteria adopted.

Sustainability is a property of a system open to interactions with its external world. It is not a fixed state of constancy, but a dynamic preservation of the essential identity of the system amidst permanent change. A small number of generic attributes may provide the foundations of sustainability.

Sustainable development is not a property but a process of directional change by which a system improves[32] through time in a sustainable way.

Development and economic growth are often confounded, but

[32] Improvement ("change for the better") is a normative concept, and thus the definition of when a change represents an improvement may differ among parties adopting different paradigms of sustainable development.

they need to be clearly differentiated; development is a qualitative process of realization of potentialities which may or may not involve economic growth (a quantitative increase in wealth).

Economic growth and matter/energy throughput must be decoupled: economic growth is not necessarily synonymous with material economic growth.

Different situations and strategies regarding sustainability of development can be categorized along the dimensions of quality of life, material economic growth, and non-material economic growth.

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