# Indicators for Sustainable Development: Theory, Method, Applications

## A Report to the Balaton Group

Hartmut Bossel

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## Background and overview

Sustainable development has become a widely recognized goal for human society ever since deteriorating environmental conditions in many parts of the world indicate that its sustainability may be at stake. But how do we know for sure? And how can we tell when we are on a path of sustainable development? We need appropriate indicators.

Finding an appropriate set of indicators of sustainable development for a community, a city, a region, a country or even the world is not an easy task. It requires knowledge of what is important for the viability of the systems involved, and how that contributes to sustainable development. The number of representative indicators should be as small as possible, but as large as essential.

Many members of the Balaton Group have been concerned with this problem for a long time, in many different countries and in many different projects. To pool and coordinate this accumulated experience, the first formal workshop on Indicators of Sustainable Development was initiated by Donella Meadows and organized at the National Institute of Public Health and the Environment (RIVM) in Bilthoven, the Netherlands in April 1996. Several smaller follow-up workshops were held to deal in particular with systems theoretical aspects, notably in September 1996 and 1997, and December 1997, supplemented by extensive e-mail exchanges. Some Balaton members pursued the subject continuously on their own and in international collaboration.

Results of this work are reported in a Report to the Balaton Group (Donella Meadows: Indicators and Information Systems for Sustainable Development. Sustainability Institute, P.O. Box 174, Hartland Four Corners, VT 05049, USA) and in the present companion report, which concentrates on development and application of a systems theoretical framework for defining indicator sets for sustainable development.

In Chapter 1, What is sustainable development? Concepts and constraints, I define sustainable development in a holistic systems sense and point to the various constraints that restrict possible development paths to accessibility space.

In Chapter 2, How to recognize sustainable development? Looking for indicators, I look at the reasons for having relevant indicators, review existing approaches for defining indicator sets, and identify major systems of societal development for which indicators are required.

In Chapter 3, What does sustainability of a system imply? Orientors of viability, I concentrate on identifying essential interests or basic orientors of systems that have to be fulfilled to some minimum degree to insure a system's viability and sustainable development.

In Chapter 4, What indicators to select? Unavoidable choice, I argue that indicators must be selected to reflect the state of satisfaction of the basic orientors. Moreover, the choice of indicators must reflect important characteristics of dynamic systems as well as ethical concerns.

In Chapter 5, Defining indicator sets: Procedure, I outline the practical steps for developing a comprehensive set of indicators of sustainable development, and for assessing viability and sustainability.

In Chapter 6, Defining and using indicator sets: Examples, I apply the approach at the level of community, state, country, region and global development. Using Worldwatch data series, a set of indicators is defined and used for computer-assisted assessment of global sustainability dynamics from 1950 to 2000.

Substantial inputs to the present report have come in particular from Wouter Biesiot and the participants of the smaller workshops: Alan AtKisson, Joan Davis, Donella Meadows, Jørgen Nørgård, John Peet, Katherine Peet, Laszlo Pinter, Aromar Revi and Bert de Vries. Especially helpful have been extensive written comments by Donella Meadows, John and Katherine Peet, Karl-Friedrich Müller-Reissmann and Bernd Hornung. Although I have tried to incorporate all ideas and suggestions, it has not always been possible to include them in a cohesive framework. The report reflects very much my own way of fitting pieces together. It is a report on work in progress, and constructive criticism, suggestions for improvement, and feedback about applications and experience are welcome.

# 1. What is sustainable development? Concepts and constraints

## 1.1. Sustainability of human society

There is only one alternative to sustainability: unsustainability. But sustainability involves a time dimension: unsustainability *now* rarely implies an immediate existential threat. Existence is threatened only in the distant future, perhaps too far away to be properly recognized. Even if threats are understood, they may not cause much concern now: there still seems to be enough time for them to disappear, or for finding solutions.

In the past, the sustainability of human society was not really at stake: the glacial change of its environment left plenty of time for adaptive response and evasion.

Threats to sustainability of a system require urgent attention if their rate of change begins to approach the speed with which the system can adequately respond. As the rate of change overwhelms this ability to respond, the system loses its viability and sustainability. The sustainability of humankind is now threatened by both of these factors: the dynamics of its technology, economy and population accelerate the environmental and social rates of change, while growing structural inertia reduces the ability to respond in time. Response time lengthens while respite time—the time available for adequate response—shortens:[1] the sustainability of human society becomes an urgent concern.

### *Sustainability in an evolving world can only mean sustainable development*

In previous times, sustainability of humankind was taken for granted and did not appear as an explicit goal. It certainly was an implicit goal: no human society has ever consciously promoted its own unsustainability.

Global developments now focus attention on sustainability as an explicit goal. But the concept has to be translated into the practical dimensions of the real world to make it operational. We must be able to recognize the presence or absence of sustainability, or of threats to sustainability, in the systems under our stewardship. We need proper indicators to provide this information, to tell us where we stand with respect to the goal of sustainability.

To *sustain* means "to maintain; keep in existence; keep going; prolong."[2] If applied only in this sense, sustainability does not make much sense for human society. Human society cannot be maintained in the same state, whatever it should be. Human society is a complex adaptive system embedded in another complex adaptive system—the natural environment—on which it depends for support. These systems coevolve in mutual interaction, and they each consist of a myriad of subsystems that coevolve in mutual interaction. There is permanent change and evolution. Moreover, this ability for change and evolution must be maintained if the systems are to remain viable (able to cope with their changing system environment) and sustainable. The sustainability goal translates more accurately into a goal of sustainable *development*.

### *Different concepts of sustainable development*

How do we define sustainable development? One of the most commonly cited definitions stresses the economic aspects by defining sustainable development as "economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs."[3] Another takes a broader view by defining sustainable development as "the kind of human activity that nourishes and perpetuates the historical fulfillment of the whole community of life on earth."[4]

There are many ways of securing sustainability, with very different consequences for the participants. Nature has successfully demonstrated sustainable development for a few billion years, with blind disregard of the fate of individuals and even species. The principle of survival of the fittest with its effectiveness and dynamics, but also its cruelty and hardship, would not be accepted as a principle for sustainable development by the majority of humankind.

Some human societies have been sustainable in their environment over long periods of time by institutionalizing systems of exploitation, injustice, and class privilege that would be equally unacceptable today for most of humankind.

If we would achieve environmental sustainability coupled with a continuation of present trends, where a small minority lives in luxury, partly at the expense of an underprivileged majority, this would be socially unsustainable in the long run because of the stresses caused by the institutionalized injustice. And an equitable, environmentally and physically sustainable society that exploits the environment at the maximum sustainable rate would still be psychologically and culturally unsustainable.

Sustainable development of human society has environmental, material, ecological, social, economic, legal, cultural, political and psychological dimensions that require attention: some forms of sustainable development can be expected to be much more acceptable to humans and, therefore, much further away from eventual collapse than others. A just and fair society, for example, is likely to be more securely sustainable than a materially sustainable brutal dictatorship.

The sustainability concept we adopt has consequences: our interpretation of the concept directs our focus to certain indicators at the neglect of others. Conversely, if we rely on a given set of indicators, we can only see the information transmitted by these indicators, and this defines and limits both the system and the problems we can perceive, and the kind of sustainable development we can achieve.

## 1.2. Sustainable development is constrained by what is accessible

There are numerous constraints that restrict societal development. A few can be negotiated to some degree; most are unchangeable. The total range of theoretical future possibilities is reduced by these constraints, leaving only a limited, potentially accessible set of options, the *accessibility space* (Fig. 1). Societal development—whatever its form—will be restricted to the remaining accessibility space. Everything outside is fiction, and only confuses the discussion. However, within this accessibility space, there is still a broad spectrum of options and possible paths. This leaves choices, and it introduces subjective choice and unavoidable ethical decisions.

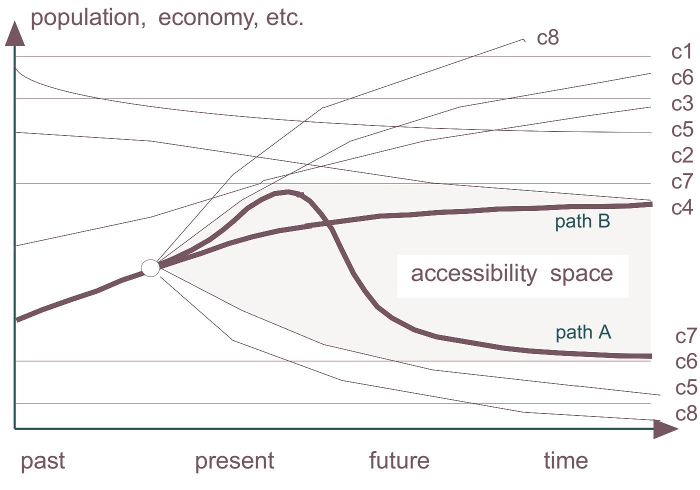


*Fig. 1. Development is constrained by various factors (see text). These constraints leave only a limited accessibility space.*

Sustainability is a dynamic concept. Societies and their environments change, technologies and cultures change, values and aspirations change, and a sustainable society must allow and sustain such change, i.e., it must allow continuous, viable and vigorous development, which is what we mean by sustainable development. The result of such adaptation as a result of selection from a wide range of possibilities cannot be foretold. Even though the factors constraining the development process and the processes driving it are known, the path of sustainable development is still the unpredictable result of an evolutionary process. The shape and form of a sustainable society must allow perpetual change in order to be sustainable; it can neither be planned nor predicted.

### *Constraints of physical conditions and laws of nature: not everything is possible*

***Laws of nature, rules of logic:*** The laws of nature and the rules of logic cannot be broken. This implies restrictions that cannot be circumvented. Examples of such restrictions are the minimum nutrient requirements for plant growth, or the maximum energy efficiencies of thermal processes. Laws of nature, logic and permissible physical processes provide a first constraint, $c_1$, on accessibility space.

***Physical environment and its constraints:*** Human society evolves within, is dependent on, and is part of the global environment. Its development is constrained by the conditions of the global environment: available space; waste absorption capacity of soils, rivers, oceans, atmosphere; availability of renewable and non-renewable resources; soil fertility and climate. Some of these are state limitations (e.g., the amount of depletable resources), others are rate limitations (e.g., the maximum rate of waste absorption). Sustainable development paths must adhere to these constraints. This is a second restriction, $c_2$, of accessibility space.

***Solar energy flow, material resource stocks:*** There is only one permanent energy supply on earth: solar energy. All currently available fossil and nuclear resources amount to a few months of global insolation, if all of the solar energy reaching the earth during those months could be captured. In sustainable development, the energy limitation is the rate of solar energy flux that can be captured and used by plants and technology. All material resources are limited to the present global supplies. They have been recycling on this earth for some four billion years. Recycling is, therefore, also an essential requirement of sustainability. These energy and material constraints are a third restriction, $c_3$, of accessibility space.

***Carrying capacity:*** Organisms and ecosystems, including humans, require certain amounts of solar energy flux, nutrients, water, and so on per unit of organism supported, either directly (plants), or indirectly as food in plant or animal biomass. The consumption rate depends on the organism and its lifestyle. In the long term, it is limited by the photosynthetic productivity of a region, i.e., the amount of plant biomass that can be produced there per year, which is determined by the resource (nutrient, water, light) that is 'in the minimum' (Liebig's Law; limiting factor). The carrying capacity is the number of organisms of a given species that can be supported by the region, given its (biomass) productivity and the demands of its organisms. The carrying capacity of a region for humans depends on their material consumption. It is not only determined by food demand, but also by the demand for other resources (water, energy, rare metals, waste absorption, and so on). For identical physical constraints, the carrying capacity would be higher in a frugal society than a wasteful one. Hence, carrying capacity is a fourth restriction, $c_4$, of accessibility. Humans can partially, and only temporarily, overcome the carrying capacity of a region by bringing in critical resources from other regions. Eventually, as a resource becomes also scarcer in other regions, this transfer would have to stop.

### *Constraints of human nature and human goals: not everything is desirable*

***Human actors:*** Humans are self-conscious, anticipatory, imaginative, creative beings. This means that they are not restricted to act in narrowly confined ways according to fixed rules of behaviour. They can invent new solutions—or they may not even see the obvious ones. This introduces as a fifth set of constraints, $c_5$, on accessibility space, a restriction to those states that are mentally and intellectually accessible. Societies which are more innovative, have a better educated and trained population, and provide a diverse and open-cultural environment, have a greater accessibility space left than others where these conditions are not found.

***Human organizations, cultures, technology:*** For a given society, and for the world as a whole, existing human organizations, cultural and political systems, available and possible technology and its systems, with their implications for behaviour and the acceptance of change, will further constrain the accessibility space. This provides a sixth set of constraints, $c_6$.

***Role of ethics and values:*** Not everything that remains accessible will be tolerated by the ethical standards, or other behavioural or cultural values and norms of a given society. This introduces a seventh set of constraints, $c_7$.

### *Constraints of time: dynamics and evolution determine pace and direction*

***Role of time:*** All dynamic processes take time. For example, building infrastructure, or introducing a new technology, or cleaning water in groundwater passage, or restoring soil fertility, or stopping population growth, all take time, posing severe restrictions on what can be done, and how quickly or slowly things can be changed. The characteristic time constants of essential processes, i.e., their characteristic rates or speeds, introduce an eighth set of constraints, $c_8$. Of particular importance is the ratio of rates of threat to rates of response: if responses cannot keep up with threats, viability and sustainability are at risk.

***Role of evolution:*** Sustainable development implies constant evolutionary, self-organizing and adaptive change. For this the widest possible spectrum of adaptive responses to new challenges should be available for potential adoption. But this means that diversity of processes and functions is one of the important prerequisites for sustainability. The greater the number of different innovative options, the better. Diversity allows timely adaptation by offering options, some of which may turn out to be better suited to cope with present conditions than others. By contrast, because of their lack of alternatives, monocultures of any kind carry the seeds of their own destruction. The available spectrum of diversity is a ninth set of constraints, $c_9$.

## 1.3. Sustainable development requires systems information

The total system of which human society is a part, and on which it depends for support, is made up of a large number of component systems. The whole cannot function properly and is not viable and sustainable if individual component systems cannot function properly, i.e., if they are not viable and sustainable. Sustainable development is possible only if component systems as well as the total system are viable.

Despite the uncertainty of the direction of sustainable development, it is necessary to identify the essential component systems and to define indicators that can provide essential and reliable information about the viability of each and of the total system.

Prudence suggests watching the viability of each of these systems. This is independent of the particular ethical or ideological view adopted: how much we value each of these systems and support their viability are different matters altogether. In fact, even pure self-interest would counsel securing best-possible knowledge of the state of the environment and the viability of the systems in it to use them for own advantage.

*Indicators provide comprehensive information about the systems shaping sustainable development*

A number of requirements follow for finding indicators of sustainable development:

- Indicators of sustainable development are needed to guide policies and decisions at all levels of society: village, town, city, county, state, region, nation, continent and world.
- These indicators must represent all important concerns: An *ad hoc* collection of indicators that just *seem* relevant is not adequate. A more systematic approach must look at the interaction of systems and their environment.
- The number of indicators should be as small as possible, but not smaller than necessary. That is, the indicator set must be comprehensive and compact, covering all relevant aspects.
- The process of finding an indicator set must be participatory to ensure that the set encompasses the visions and values of the community or region for which it is developed.
- Indicators must be clearly defined, reproducible, unambiguous, understandable and practical. They must reflect the interests and views of different stakeholders.
- From a look at these indicators, it must be possible to deduce the viability and sustainability of current developments, and to compare with alternative development paths.
- A framework, a process and criteria for finding an adequate set of indicators of sustainable development are needed.

# 2. How to recognize sustainable development? Looking for indicators

## 2.1. The difficulty: so many systems and variables to watch

The world around us is a complex adaptive system composed of a multitude of systems that interact in various ways. While each has a certain measure of autonomy, each also depends on the functions of other systems, and plays a part in supporting other systems and the functioning of the total system. Plants recycle carbon dioxide—a waste product of all organisms and human technology—into biomass with the help of solar energy. Biomass serves as food, fodder and fuel for animals and humans. Microorganisms in soil and water decompose wastes into their mineral constituents, which then serve as plant nutrients. Cells cooperate in specialized organs like the heart or liver, roots or flowers. The different organs cooperate to make an organism a viable system in its particular environment. Human individuals form systems such as families, communities, organizations, corporations, states and cultures. When we speak of sustainable development, we clearly have to include environmental, economic, technological, social, political and psychological aspects. The corresponding systems are linked in various and often crucial ways in one complex total system.

*Recognizing patterns: understanding from a few indicators*

A deeper look at the world reveals many relationships and component systems that are important to the operation and viability of the total system, even though they are not immediately obvious. A systems view is, therefore, required for capturing and understanding essential relationships.

The crucial part is identifying the essential relationships in a system. This requires a process of aggregation and condensation of available information, and the directed search for missing information needed for a comprehensive description of the system. This process of systems analysis is guided by the particular task, and the knowledge and experience of the analysts. It requires choice and selection at every stage. A circumspect and self-critical approach by analysts is essential. It should be coupled with independent analysis by others with different points of view, representing in particular the interests of those who may be affected by policy decisions. The result of this effort is some kind of a model—a mental model, a verbal description, or a more formal mathematical or computer model. This model is then used to identify indicators providing essential information about the system.

The process of condensing large amounts of information to a recognizable pattern of a few indicators is not unique to systems analysis. It is actually accomplished continuously by each of us. It is only in this way that we can comprehend events around us and respond appropriately. Indicators facilitate orientation in a complex world.

We live by such indicators. A smile signals friendliness; a gray sky, possible rain; a red traffic light, danger of collision; the hands of a watch, the time of day; a high body temperature, illness; rising unemployment, social trouble. The more complex the little world in which each of us lives, the more indicators we have to watch. If we want to assess how we are doing as individuals or as society, we have to look at indicators that provide relevant information about current and possible future developments.

### *Indicators summarize complex information of value to the observer*

Indicators are our link to the world. They condense its enormous complexity to a manageable amount of meaningful information, to a small subset of observations informing our decisions and directing our actions. If we have learned to watch the relevant indicators, we can understand and cope with our dynamic environment. If we follow the wrong signals, we get confused or misled, responding inappropriately, against our intrinsic interests and intentions, going in a direction in which we don't want to go.

Indicators represent valuable information. In the course of growing up, in our formal education, and in learning to cope with our specific personal and professional environment we have learned the meaning and significance of the indicators we use in our daily lives. The indicators we watch mean something to us, they are of value to us because they tell us something that is in some way important to us. They help us to construct a picture of the state of our environment on which we can base intelligent decisions to protect and promote what we care about. Indicators, therefore, are also an expression of values.

### *Being fully informed means watching relevant indicators for all vital aspects of a development*

Essential indicators are not always obvious. Learning to handle a complex system means learning to recognize a specific set of indicators, and to assess what their current state means for the health, or viability, of the system. Often this learning of indicators is intuitive, informal, subconscious: a mother learning to recognize and to respond to the signals from her newborn baby, or a farmer learning to recognize the signals from the animals, plants and soils under his or her care.

Intuitive learning is not sufficient for handling many of the complex systems that humans have constructed, such as airplanes, production systems, and the economy. In fact, such systems require specific instruments providing indicator information to the humans in charge of them, such as air speed indicators, pressure and temperature gauges, cost-of-living and employment indicators, or the Dow-Jones index. Essential indicators are often not obvious or intuitive. Sometimes they are eventually revealed by trial and error. Often, we have to search for them, based on our mental model of the system and its processes.

### *Two types of indicators: for the viability of a system and for its contribution to the performance of another system*

Indicator sets about a given system are determined by two distinct requirements: (1) they have to provide vital information providing a picture about the current state and corresponding viability of that system; and (2) they have to provide sufficient information about the system's contribution to the performance of other systems that depend on them. This is particularly obvious where humans try to manage systems for their own goals and interests. Here, they need indicators not only to inform them of the state of the system they are managing (e.g., a forest, an airplane), but also relevant indicators to successfully intervene and correct system behaviour in accordance with given objectives, and to determine the relative success of this intervention (e.g., maximizing economic yield, reaching a given destination). In other words, indicator sets are determined by (1) the system itself, and (2) the interests, needs, or objectives of the system(s) depending on them.

In complex real systems, this is a recursive relationship: systems depend on other systems that depend on yet another set of systems, and so on. The general relationship is shown in Fig. 2.

An airplane is a good example of this dual role of indicators. There are basically two groups of instruments providing information about (1) the current state and functional integrity of the airplane itself, and (2) its position and heading with respect to the destination chosen by the pilot. Moreover, these indicators will not all be of equal importance to the pilot and to the operation of the airplane. Some of these, like airspeed and altitude indicators, require continuous attention, while others, like fuel and oil pressure gauges, are only needed for occasional checks.

The human societal system, its component systems, and the resource and environmental system on which they depend, are complex dynamic systems. Just like the pilots of aircraft, the human individuals and organizations who run these systems need comprehensive sets of indicators providing essential information about (1) the state (and corresponding viability) of these systems themselves, and (2) about their position with respect to individual and societal goals. The latter point means that human goals and values figure prominently in the definition of indicator sets of human societal development, and in the attention focused on each of the indicators.

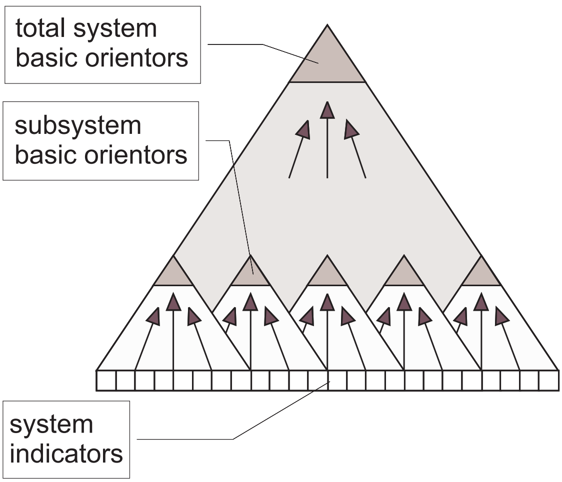


*Fig. 2. In systems that depend on subsystems, viability has two separate aspects: (1) viability of the subsystem, and (2) the subsystem's contribution to the performance of the system. This is a recursive relationship: subsystems may depend on sub-subsystems, and so on.*

## 2.2. A critique of popular indicators of development: missing vital information

### *Keep it simple: pitfalls of watching a single indicator*

Paraphrasing Albert Einstein, indicator sets should be as simple as possible, but not simpler. The simplest solution would be to agree on a single indicator. Would that work?

For ages people have been judged by a single indicator: their wealth. But that single magic figure of x million dollars, or y hundred hectares of land, or z head of cattle implicitly expressed much more than property: it expressed the ability to buy sufficient food, to build a comfortable house, to feed even a large family, to live in luxury, to educate children, to pay for health care, and to support oneself in old age. And it implied that under these circumstances one could be reasonably happy. In other words, under prevailing conditions, wealth could be used as an aggregate indicator for completely different dimensions of life contributing to general happiness. But it could not account for personal tragedy or disability, and wealth would fail as an indicator for happiness if, say, the children were killed in an accident. In real life we usually need more than one indicator to capture all important aspects of a situation. A single indicator can never tell the whole story.

*A single indicator like GDP cannot capture all vital aspects of sustainable development*

The fascination with a single indicator has carried over to economics and national development, with a rather bizarre twist: economists have not focused on per capita wealth (of financial assets, land or resources), but—in addition to watching inflation and unemployment rates—devote most of their attention to an indicator that essentially measures the rate at which natural resource wealth is being depleted—the faster, the better. This is the GDP indicator—gross domestic product—the total money value of the annual flow of goods and services produced in an economy. This includes all goods and services, irrespective of their contribution to national development: social goods (such as education, food and housing) as well as social bads (such as cost of crime, pollution, car accidents, disability and poor health). Since, with current technology, each of these goods and services is associated with significant consumption of non-renewable resources and generation of environmental pollution, GDP is now mainly a measure of how fast resources are squandered and converted into money flows, irrespective of their effect on society.[5] Hardly an indicator of national wealth and well-being!

*Aggregate indexes are an improvement, but aggregation can conceal serious deficits*

In response to these obvious shortcomings of the popular GDP, various groups have sought to define aggregate indicators that present a more accurate picture of material well-being.[6] In the Index of Sustainable Economic Welfare (ISEW—later evolved into the Genuine Progress Indicator, GPI[7]), GDP is corrected by subtracting (rather than adding) social bads (like the cost of pollution clean up or car accidents), and adding (rather than ignoring) the value of unpaid services (e.g., in households and communities). Other aggregate indicators include concerns beyond money flows. The UNDP's Human Development Indicator (HDI), for example, includes literacy and life expectancy.

These are important improvements but they cannot remove a fundamental deficiency of aggregate indicators: aggregation may hide serious deficits in some sectors, which actually threaten the overall health of the system. And aggregate indicators become even more questionable when they require adding apples and oranges (as in the HDI), i.e., items that cannot be measured in the same units (such as money flows). Why not use separate indicators in the first place?

### *Measuring sustainability: ecological footprint and barometer of sustainability*

An aggregate indicator that makes physical sense is the Ecological Footprint or the almost equivalent Sustainable Progress Index (SPI).[8] It measures the total land area that is required to maintain the food, water, energy and waste-disposal demands per person, per product or per city. This is an excellent summary indicator of the major environmental impacts of economic activity, but it does not—and is not meant to—capture the social dimensions of sustainable development, for example.

In order to evaluate simultaneously both the environmental and social components of sustainable development, the barometer of sustainability has been developed.[9] In this two-dimensional graph, the states of ecosystem well-being and human well-being are plotted on relative scales from 0 to 100, indicating the range from bad to good conditions. The location of the point defined by these two values gives an indication of sustainability (or unsustainability). In an application for Manitoba, Canada,[10] ecosystem well-being is computed by aggregating six indicators, while human well-being uses 28 indicators.

### *Ad hoc or trial-and-error selection of indicators is inadequate*

In response to the deficiencies of the aggregate indicator concept, some researchers prefer to use more or less extensive lists of indicators covering the problem area under investigation.[11] While they are an improvement over the aggregate indicator concept, these lists must be criticized on several counts: (1) they are derived *ad hoc*, without a systems theoretical framework to reflect the operation and viability of the total system; (2) they always reflect the specific expertise and research interest of their authors; (3) as a consequence of (1) and (2), they are overly dense in some areas (multiple indicators for essentially the same concern), and sparse or even empty in other important areas. In other words, they are not a systematic and complete reflection of the total system, i.e., human society in interaction with its natural environment.

### *Pressure–state–response frameworks fail to account for system relationships and dynamics*

In an attempt to be more systematic, the PSR (pressure, state, response)[12] and PSIR (pressure, state, impact, response) frameworks have been introduced and are widely applied to sustainable development problems.[13] In this approach, isolated chains of cause and effect are identified for a particular environmental problem and corresponding indicators are monitored. For example: $CO_2$-emissions (pressure) → ( $CO_2$ concentration of the atmosphere (state) → ( global temperature (impact) → ( carbon tax (response).

The most serious objection to this approach is that it neglects the systemic and dynamic nature of the processes, and their embedding in a larger total system containing many feedback loops. Representation of impact chains by isolated PSIR-chains will usually not be permissible, and will often not even be an adequate approximation. Impacts in one causal chain can be pressures, and in another can be states, and vice versa. Multiple pressures and impacts are not considered. The real, usually nonlinear relationships between the different components of a chain cannot be accounted for. States, and rates of change (stocks and flows) are treated inconsistently.[14] For example, a PSIR chain of the $CO_2$-emissions problem would not account for the facts that $CO_2$-concentration is only partially caused by human emissions, that global temperature is only partially determined by $CO_2$-emissions, that a carbon tax may be introduced for other reasons, and that this tax has many other (economic and social) repercussions besides affecting $CO_2$-emissions.

### *A systems approach is required to structure the search for indicators*

The conclusion from this brief look at indicator schemes is that none of them is adequate for the purpose defined in the previous section: (1) to provide all essential information about the viability of a system and its rate of change, and (2) to indicate the contribution to the overall objective (e.g., of sustainable development). There is a general awareness of these shortcomings in the research community, and it has led to the formulation of the Bellagio Principles as “guidelines for practical assessment of progress toward sustainable development”[15] (see Box on Bellagio Principles).

Realizing the inadequacy of current approaches to indicators of sustainable development, we must analyze the entire complex of problems and tasks more carefully. This requires a reasonably detailed (mental or formal) model of the total system and its components. There are three separate tasks:

1. We must identify the *major systems* that are relevant in the context of sustainable development;
2. We must develop an approach for identifying *indicators* of viability and sustainability of these systems; and
3. We must think about how to use this information for *assessing viability and sustainability* of human development at different levels of societal organization.[16]

## *Bellagio Principles—Guidelines for Practical Assessment of Progress Toward Sustainable Development*

*(from Hardi, P. and T. Zdan, 1997. Assessing Sustainable Development: Principles in Practice. Winnipeg: IISD)*

1. GUIDING VISION AND GOALS

   Assessment of progress toward sustainable development should:

   - be guided by a clear vision of sustainable development and goals that define that vision.

2. HOLISTIC PERSPECTIVE

   Assessment of progress toward sustainable development should:

   - include review of the whole system as well as its parts;
   - consider the well-being of social, ecological and economic subsystems, their state as well as the direction and rate of change of the state, of their component parts, and the interaction between parts;
   - consider both positive and negative consequences of human activity in a way that reflects the costs and benefits for human and ecological systems, both in monetary and non-monetary terms.

3. ESSENTIAL ELEMENTS

   Assessment of progress toward sustainable development should:

   - consider equity and disparity within the current population and between present and future generations, dealing with such concerns as resource use, overconsumption and poverty, human rights, and access to services, as appropriate;
   - consider the ecological conditions on which life depends;
   - consider economic development and other non-market activities that contribute to human and social well-being.

4. ADEQUATE SCOPE

   Assessment of progress toward sustainable development should:

   - adopt a time horizon long enough to capture both human and ecosystem time scales, thus responding to current short-term decision-making needs as well as those of future generations;
   - define the space of study large enough to include not only local but also long distance impacts on people and ecosystems;
   - build on historic and current conditions to anticipate future conditions: where we want to go, where we could go.

5. PRACTICAL FOCUS

   Assessment of progress toward sustainable development should be based on:

   - an explicit set of categories or an organizing framework that links vision and goals to indicators and assessment criteria;
   - a limited number of key issues for analysis;

- a limited number of indicators or indicator combinations to provide a clearer signal of progress;
- standardizing measurement wherever possible to permit comparison;
- comparing indicator values to targets, reference values, ranges, thresholds or direction of trends, as appropriate.

6. OPENNESS

   Assessment of progress toward sustainable development should:
   - make the methods and data that are used accessible to all;
   - make explicit all judgments, assumptions and uncertainties in data and interpretations.

7. EFFECTIVE COMMUNICATION

   Assessment of progress toward sustainable development should:
   - be designed to address the needs of the audience and set of users;
   - draw from indicators and other tools that are stimulating and serve to engage decision-makers;
   - aim, from the outset, for simplicity in structure and use of clear and plain language.

8. BROAD PARTICIPATION

   Assessment of progress toward sustainable development should:
   - obtain broad representation of key grassroots, professional, technical and social groups, including youth, women and indigenous people to ensure recognition of diverse and changing values;
   - ensure the participation of decision-makers to secure a firm link to adopted policies and resulting action.

9. ONGOING ASSESSMENT

   Assessment of progress toward sustainable development should:
   - develop a capacity for repeated measurement to determine trends;
   - be iterative, adaptive and responsive to change and uncertainty because systems are complex and change frequently;
   - adjust goals, frameworks and indicators as new insights are gained;
   - promote development of collective learning and feedback to decision-making.

10. INSTITUTIONAL CAPACITY

    Continuity of assessing progress toward sustainable development should be assured by:
    - clearly assigning responsibility and providing ongoing support in the decision-making process;
    - providing institutional capacity for data collection, maintenance and documentation;
    - supporting development of local assessment capacity.

## 2.3. Sustainable development is coevolution of human and natural systems

*In a systems view of sustainable development six essential subsystems can be distinguished*

In order to define an indicator set for the assessment of societal development, we must first identify the different relevant sectors or subsystems of the societal system. We must include the systems that constitute society as well as the systems on which human society depends. A useful distinction of subsystems is the following:[17]

- ***Individual development*** (civil liberties and human rights, equity, individual autonomy and self-determination, health, right to work, social integration and participation, gender and class-specific role, material standard of living, qualification, specialization, adult education, family and life planning horizon, leisure and recreation, arts)
- ***Social system*** (population development, ethnic composition, income distribution and class structure, social groups and organizations, social security, medical care, old age provisions)
- ***Government*** (government and administration, public finances and taxes, political participation and democracy, conflict resolution (national, international), human rights policy, population and immigration policy, legal system, crime control, international assistance policy, technology policy)
- ***Infrastructure*** (settlements and cities, transportation and distribution, supply system (energy, water, food, goods, services), waste disposal, health services, communication and media, facilities for education and training, science, research and development)
- ***Economic system*** (production and consumption, money, commerce and trade, labour and employment, income, market, interregional trade)
- ***Resources and environment*** (natural environment, atmosphere and hydrosphere, natural resources, ecosystems, species, depletion of nonrenewable resources, regeneration of renewable resources, waste absorption, material recycling, pollution, degradation, carrying capacity)

Other ways of subdividing the total system are possible.

In order for the total system (the human system embedded in the natural system) to be viable, each of these essential subsystems must be viable: the viability of the total system depends on the proper functioning of the subsystems. The task will be to find relevant indicators for each subsystem. Moreover, we must identify indicators that provide information about the contribution of each subsystem to the viability of the total system.

*The six subsystems correspond to potentials that must be sustainably maintained*

Although other classifications are possible, this identification of subsystems is not arbitrary. These subsystems are all essential parts of the anthroposphere, i.e., the sphere that is affected by and affects human society. The major relationships between the six subsystems are shown in Fig. 3. Each of these subsystems can be viewed as representing a certain type of potential that is vital to the development of the total system. In this connection, the term potential denotes a stock or capital of a vital asset, which can grow or depreciate, and must be maintained in good state in order to contribute its share to the development of the total system.

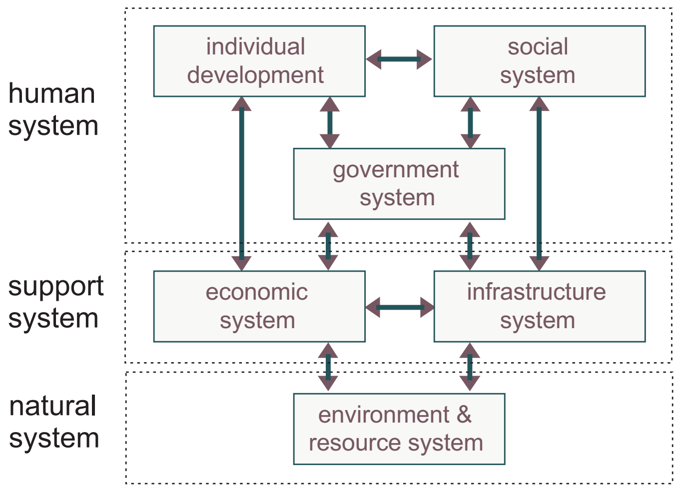


*Fig. 3. The six major systems of the anthroposphere and their major relationships. These six sector systems can be aggregated to the three subsystems: human system, support system and natural system.*

***Individual potential*** describes the potential for competent individual action as produced by—and producing—the possibilities for individual development. It is the accumulated result of tradition and culture as well as socio-political and economic conditions.

***Social potential*** denotes something less tangible: the ability to deal constructively with social processes, and to employ them for the benefit of the total system. This has a strong cultural component determining social coherence and relationships. It includes such aspects as honesty, trust, competence and efficiency.

***Organizational potential,*** as manifest in the know-how and performance standards of government, administration, business and management, is vital for effective resource use (natural and human) for the benefit of the total system.

***Infrastructure potential*** denotes the stock of built structures like cities, roads, water supply systems, schools and universities. It is the essential backbone of all economic and social activity.

***Production potential*** of the economic system includes the stock of production, distribution and marketing facilities. It provides the means for all economic activity.

***Natural potential*** represents the stock of renewable and nonrenewable resources of materials, energy and biosystems, including the capacity for waste absorption and regeneration.

*The six subsystems can be aggregated to three subsystems: human system, support system, natural system*

As we shall see below, for each subsystem we need a number of indicators to capture all aspects of its viability and sustainability and of their contributions to viability and sustainability of the total system. The total number of indicators increases with the number of subsystems we include. To keep the number of indicators at manageable level, we can aggregate the six sector systems to three subsystems:

- human system = social system + individual development + government
- support system = infrastructure + economic system
- natural system = resources + environment

These three subsystems correspond to the three categories of capital that are often used in analyses of the total system: human capital, structural (built) capital and natural capital.

# 3. What does sustainability of a system imply? Orientors of viability

## 3.1. Using systems theory to identify the vital aspects of sustainable development and relevant indicators

### *The task: defining a framework and a process for finding a set of indicators*

We now know what we need and want as indicators: system variables that provide us with all essential information about the viability of a system and its rate of change and about how that contributes to sustainable development of the overall system.

It is more difficult to actually define a suitable set of indicators for a given application. In what follows, a framework and a process for defining a comprehensive set of indicators for sustainable development will be presented.[18] For this, some essential system concepts are needed.

### *Essential system concepts*

A *system* is anything that is composed of system *elements* connected in a characteristic system *structure* (Fig. 4). This configuration of system elements allows it to perform specific system *functions* in its system *environment*. These functions can be interpreted as serving a distinct system *purpose*. The system *boundary* is permeable for *inputs* from and *outputs* to the environment. It defines the system's *identity* and *autonomy*.

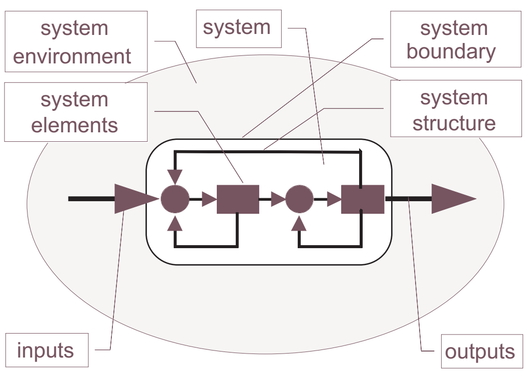


*Fig. 4. A system interacts with its system environment through system inputs and outputs.*

It is useful to distinguish different categories of systems. Identifying distinct qualitative differences, we can categorize systems as follows:[19]

- ***Static systems.*** They do not interact with their environment and do not change. Examples: a rock or a chair.
- ***Metabolic systems.*** They require a throughput of energy, matter or information to exist. Examples: a waterfall, a flame, a radio or a motor.
- ***Self-supporting systems.*** They have the ability to secure necessary resources (matter, energy and information). Examples: simple organisms or exploration robots running on solar energy.
- ***Selective systems.*** They can respond selectively to environmental challenges. Examples: organisms responding selectively to light, heat, water, acidity, and so on.
- ***Protective systems.*** They can protect themselves from adverse influences. Examples: organisms using or even constructing shelters.
- ***Self-organizing systems.*** They can change their system structure to adapt to changes in their environment. Examples: plants, animals, ecosystems or human organizations.
- ***Non-isolated systems.*** They modify their behaviour in response to the presence and activities of other systems. Examples: competing predators or firms.
- ***Self-reproducing (autopoietic[20]) systems.*** They can reproduce systems of their own kind. Examples: body cells, populations or human organizations and culture.
- ***Sentient systems.*** They can experience pain, stress, emotions, and so on. Examples: animals and humans.
- ***Conscious systems.*** They can reflect about their actions and subsequent impacts. Examples: humans and primates.

This sequence also indicates a sequence of development stages from the simple to the complex, with the more complex systems having most if not all of the properties of their predecessors.

### *Hierarchy and subsidiarity facilitate efficient operation*

Systems are termed complex if they have an internal structure of many qualitatively different processes, subsystems, interconnections and interactions. Besides assuring their own viability, the individual systems that are part of a complex total system specialize in certain functions that contribute to the viability of the total system. Viability of subsystems and the total system requires that subsystem functions and interactions are organized efficiently (or at least effectively). In the evolution of complex systems two organizing principles in particular have established themselves: hierarchy and subsidiarity. They can be found in all successful complex systems: biological, ecological, social, political, technological.

*Hierarchical organization* means a nesting of subsystems and responsibilities within the total system. Each subsystem has a certain autonomy for specific actions, and is responsible for performing certain tasks contributing to the viability of the total system. For example, body cells are relatively autonomous subsystems, but contribute specific functions to the operation of particular body organs, which in turn contribute to the viability of an organism.

*Subsidiarity* means that each subsystem is given the responsibility and the means for keeping its own house in order within the range of its own abilities and potential. Only if conditions occur that cannot be handled by the subsystem would the suprasystem step in and help.

### *Subsystems contribute to the viability of the total system*

Only healthy, viable systems can develop sustainably. But it is not enough to be concerned with the viability of individual systems: there are no isolated systems in the real world; all systems depend in one way or another on other systems. Hence their viability and ultimately the viability of the total system are also preconditions for sustainable development. This means that a holistic system view must be adopted in the search for indicators.

The principles of hierarchical organization and subsidiarity require that each subsystem have a certain measure of autonomy. In its particular system environment, each subsystem must be viable. The total system can only be viable if each of the subsystems supporting it is viable. For example, a region can only be viable if its economic system is viable. This has implications for the understanding and management of sustainable development: we must identify the subsystems that are essential for the functioning of the total system, and must determine subsystem variables (indicators) that can provide essential information about the viability of each subsystem. This may require defining a set of indicators that mirrors the hierarchy of systems.

An example: There is more to a successful football team than a collection of healthy football players. Each subsystem must also contribute its characteristic share to the viability of the total system. And the viability of the total system will be reflected by indicators that may bear no relationship to the viability of the subsystems. The viability of the football team will be reflected by its wins and losses over a season, by the crowds it attracts, and the net proceeds it generates.

Note that this way of looking at complex systems is recursive: If necessary, we can apply the same system/subsystem dichotomy of viable systems again at other organizational levels (see Sec. 2.1 and Fig. 2). For example, a person is a subsystem of a family; a family is a subsystem of a community; a community is a subsystem of a state; a state is a subsystem of a nation, and so on.

### *Essential information about system viability and performance is contained in (1) the states (stocks) and (2) the rates of change (flows) of a system*

Despite distinct qualitative differences, and an enormous variety of complex system structures, systems share some basic elements that allow analyzing them with the same basic tools of systems analysis. In the following, the concepts of the theory of dynamic systems[21] will be in the foreground, since sustainable development implies dynamic change of a multitude of physical and non-physical variables. Although other system descriptions of non-material processes such as the cognitive and communicative processes of social systems are possible,[22] the theory of dynamic systems can provide an adequate base for selecting indicators also in these cases (by dealing with knowledge stocks, organizational potential, degree of communication, and the like).

Observation as well as systems theory provide some insight into the general nature of indicators. There are just three types: indicators corresponding to states, rates and converters. The first type of indicator provides information of *system states* (stocks or levels such as the content of a fuel tank or the size of a population). The second type of indicator monitors the *rates of change* of system state (flows, such as current fuel consumption per minute or food sales per month). The third type provides information obtained by appropriate *conversion* of state and rate information (such as average per capita food consumption, computed from total food sales per month and the size of the population). Such indicators are often important, but since they can be obtained by measurement of states and rates and their proper conversion, the choice of representative indicators really boils down to identifying states and rates that provide relevant information about system viability: we don't have to use every variable in the system as an indicator, only a very limited set. But the choice of that set is a real challenge.

In the context of sustainable development, indicators that disclose impending threats are of particular relevance. Specifically, ratios comparing the rate of system response to the rate of threatening change can be used as crucial indicators (Biesiot indicators). The system is sustainable if such ratios are greater than or equal to one; it is unsustainable if they are less than one (more on this in Sec. 4.3).

Indicator information can be quantitative (hard numbers) or qualitative (e.g., sufficient food or substandard education). In the end, any hard number must be translated to a qualitative statement anyway in determining whether that indicator contributes to system viability or goal achievement. This brings in unavoidably subjective valuation.

### *Viability is determined both by the system and its environment*

*Health* means "physical and mental well-being; soundness; freedom from defect, pain, or disease; normality of mental and physical functions."[23] And *viable* is defined as "able…to live and develop; able to take root and grow."[24] When we talk about a viable system, we mean that this system is able to survive, be healthy and develop in its particular system environment. In other words, system viability has something to do with both the system and its properties, and with the system environment and its properties. And since a system usually adapts to its environment in a process of coevolution, we can expect that the properties of the system's environment will be reflected in the properties of the system. Also, viability obviously implies sustainability (and *vice versa*). Here, both terms will be used interchangeably.

A system can only exist and prosper in its environment if its structure and functions are adapted to that environment. If a system is to be successful in its environment, the particular features of that environment must be reflected in its structure and functions. The form of a fish and its mode of motion reflect the laws of fluid dynamics of its aquatic environment, and the legal system of a society reflects the social environment in which it developed.

Indicators of sustainable development must inform us about the state of the system we are concerned about. Since that state is significantly determined by the system's environment, the indicators must reliably capture important aspects of the system's interaction with its environment. Indicators are related to the system environment, and it makes sense to start the search by first looking at properties of system environments.

## 3.2. Fundamental properties of system environments

*General properties of system environments must be reflected in fundamental orientations of systems*

There is obviously an immense variety of system environments, just as there is an immense variety of systems. But could it be that all of these environments have some common general properties? If that were the case, we could expect their reflections as basic system needs or system interests in all systems that have been shaped by their environments. These reflections would orient not just structure and function of systems, but also their behaviour in the environment. Moreover, with proper attention to these fundamental orientations or basic orientors of systems toward general properties of their environment, we could design systems to be successful in a given environment.[25] The indicators we are looking for would have to reflect how well the basic system needs or basic orientors are satisfied under given circumstances.

Let us first determine general properties of system environments. In Sec. 3.3, we will consider how systems have to respond to these properties, i.e., which system orientors can be expected to shape system structure, function and behaviour (see Box, Indicators, orientors and sustainable development).

*Indicators, orientors and sustainable development*

As humans we use various *indicators* to guide our decisions and actions. Indicators are quantitative or qualitative measurements of the state of something that is important to us, like our body temperature, heart beat or blood pressure.

But why are these indicators important? Because they provide information about the state of our health. And why do we want to have information about our health? Because it is vitally important to our existence. The concern for health and, more fundamentally, for existence represents very important interests that orient most of our decisions and actions, directly or indirectly. We use the term *orientors* to represent such interests, values, criteria or objectives. Orientors are labels for certain categories of concerns or interests. Different systems may have the same orientors, but would have different corresponding indicators. We speak of the health of plants, for example, but might use the colour of their leaves as an appropriate indicator.

Orientors are mostly general terms like health, existence, freedom, security, and so on that represent important interests of people or systems in general, but which cannot usually be measured directly. We can only infer their state of fulfillment from observing appropriate indicators, like body temperature, or leaf colour, or gross national product, or rate of inflation, or crime rate. Thus, if the thermometer indicates a temperature of 41 degrees C, we know that the orientor *health* of a human being is in jeopardy.

It does not make much sense to develop indicator systems without explicit reference to the orientors about which they are to provide information. But that means starting by first analyzing the fundamental interests or orientors of the system for which we want to define indicators. The set of indicators we pick should provide complete and reliable information about satisfaction—or lack thereof—of all orientors. If we need indicators for sustainable development, we should be clear about what we mean by this concept, and what orientors would have to be satisfied to ensure a path of sustainable development. Appropriate indicators will follow from this analysis.

Sustainable development is a property of viable systems: if a system is viable in its environment, it will be sustainable. Hence, we first look for the orientors of viable systems. It turns out that viability of a system requires fulfillment of a set of *basic orientors* that are identical across all systems (see main text). This list of basic orientors can be used to develop a checklist for defining indicators for a whole range of diverse applications (see Table 4). If we follow that checklist in searching for suitable indicators, we can be reasonably certain that everything of importance has been considered.

The theory behind this approach—orientation theory—was developed in the 1970s in an effort to understand and analyze the diverging visions of the future and normative interests of different societal actors (political parties, industry, environmental NGOs), and to define criteria and indicators for sustainable development (Bossel 1977; 1978; 1987; 1998). Besides numerous applications in these areas, the orientor concept has recently been applied extensively in ecosystem studies (e.g., F. Müller, M. Leupelt (eds.), 1998. *Eco targets, goal functions, and orientors*, Berlin, Heidelberg, New York: Springer).

*System environments are characterized by six fundamental environmental properties*

There are various ways of determining fundamental environmental properties. In physical environments (e.g., the natural environment), we can analyze the physical signals we receive from the environment (e.g., by various instruments of measurement). Six fundamental properties of relevance to systems are found (see Box, Properties of system environments and Fig. 5).

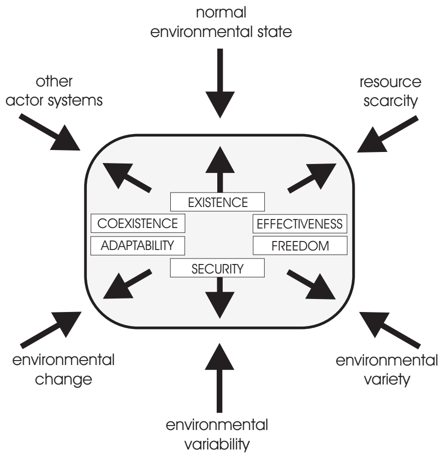


*Fig. 5. Fundamental properties of system environments and their basic orientor counterparts in systems.*

*Properties of system environments*

***Normal environmental state:*** The actual environmental state can vary around this state in a certain range.

***Resource scarcity:*** Resources (energy, matter and information) required for a system's survival are not immediately available when and where needed.

***Variety:*** Many qualitatively different processes and patterns of environmental variables occur and appear in the environment constantly or intermittently.

***Variability:*** The state of the environment fluctuates around the normal environmental state in random ways, and the fluctuations may occasionally take the environment far from the normal state.

***Change:*** In the course of time, the normal environmental state may gradually or abruptly change to a permanently different normal environmental state, i.e., it shifts to a different normal environmental state.

***Other systems:*** The environment contains other actor systems whose behaviour may have system-specific (subjective) significance for a given actor system.

Let us use a family as an example. *Normal environmental state:* A family living in a small town in a particular European country has to deal with specific economic, social, cultural, legal and political environments different from those, say, in India. *Resource scarcity:* The family needs money, water, food, electricity, consumer goods, medical services, sanitation and so on, all of which can only be secured with considerable effort. *Variety:* The family has to exist in an environment containing a host of very different neighbours, different shops and a multitude of social and cultural offerings. *Variability:* A new neighbour moves in, or members of the family become ill, change their friends, lose their jobs, or have to move. *Change:* Economic and social conditions change, new technologies enter the house and the workplace, the members of the family age. *Other systems:* The family has to care for their pets and aging parents and accommodate the interests of an employer, or of neighbours, of other drivers in traffic.

### *Each of the environmental properties is unique*

We could analyze the environments of other systems—a business, a forest ecosystem, a tree, a Mars lander, a child, a cow, a nation. We would always find the same fundamental properties of the respective environments. It becomes clear from such examples that we are indeed discussing very general properties of all system environments. Other fundamental properties do not appear to exist.

These fundamental properties of the environment are each unique, i.e., each property cannot be expressed by any combination of other fundamental properties. If we want to describe a system's environment *fully*, we have to say something about *each* of these properties: what is the normal environment? what resources are available in the environment? how rare are they? how are they distributed? what is the diversity and variety of the environment? how variable is it? what are the trends of change in the environment? what other actor systems have to be respected in one way or another?

The specific content of these fundamental environmental properties is, however, system-specific. The same physical environment presents different environmental characteristics to different systems existing in it. For example, in a meadow environment shared by cows and bees, resources mean grass to the cow, and nectar and pollen to the bee; other systems mean other cows and the farmer to the cow, and other nectar-collecting insects to the bee, and so on.

## 3.3. Fundamental orientations of systems: basic orientors

*Environmental and system properties cause distinct orientations in systems*

Systems must be compatible with their system environment and its characteristic properties in order to be viable and to exist sustainably. The environmental properties can, therefore, be viewed as imposing certain requirements and restrictions on systems, which orient their functions, development and behaviour.

Examples: The physical properties of different *environments* (sea, land, desert, arctic) enforce attention to an orientation EXISTENCE, causing organisms to avoid environments with which they are not compatible. *Resource scarcity* (water, land and energy) imposes an orientation of EFFECTIVENESS, causing humans to develop effective and efficient means of using scarce resources. The *diversity and variety* of environments cause an orientation of FREEDOM OF ACTION, allowing humans and human organizations to respond selectively and appropriately to a multitude of environmental challenges. The unpredictable *variability* of the weather imposes an orientation of SECURITY on humans and animals, causing search for shelter and food storage. Eventual *change* in the environment (partly a result of the coevolution of systems) causes an orientation of ADAPTABILITY, enabling organisms, ecosystems and human organizations to cope with changing environments by changing their own structure and processes. The presence and behaviour of *other systems* in the same environment causes an orientation of coexistence, enabling animals and humans to interact appropriately with kin, competitors or predators, and so on.[26]

Specific properties of systems may also impose certain orientations. *Self-reproducing systems* such as organisms and populations have to pay attention to an orientation of REPRODUCTION and replication at either the level of the individual or the population, or both. *Sentient beings* (animals and humans) can experience stress and pain and other emotions, and corresponding PSYCHOLOGICAL NEEDS appear as a separate orientation. *Conscious beings* (mainly humans) can reflect about their own actions and their impacts, and make conscious choices that necessitate RESPONSIBILITY as an orientation.

### *Basic orientors represent basic system interests*

Corresponding to the six fundamental environmental properties, there are six *environment-determined basic orientors* (existence, effectiveness, freedom of action, security, adaptability, and coexistence) that apply to all autonomous self-organizing systems, plus three *system-determined basic orientors* (reproduction, psychological needs, and responsibility) that are peculiar to self-reproducing (autopoietic), sentient and conscious beings. The basic orientors and their relationship to the corresponding properties of the system environment[27] are summarized below (see box, Basic orientors of systems).

Let us use a family as an example. EXISTENCE: The family should be compatible with its natural, physical, social and economic environment, should be able to communicate with others, and should be within reach of necessary resources. EFFECTIVENESS: It should be able to earn money, buy food, fuel and goods, and obtain water, sanitation and medical services, all with a reasonable effort. FREEDOM OF ACTION: It should be able to cope with a great variety of different situations, i.e., different people, different situations at home, at work and elsewhere. SECURITY: It should have shelter and clothing, and be able to protect itself from unpredictable sudden fluctuations of its normal environment such as accident or illness, loss of job, and interruption of water, power or food supply. ADAPTABILITY: It should prepare for possible change by securing a broad education and job qualifications, and have the ability to adopt a different lifestyle, if necessary. COEXISTENCE: It has to coexist with other individuals and families; this requires social skills and consideration of the interests of others. REPRODUCTION: Individuals as well as populations are self-reproducing systems and must have the opportunity and the means to regenerate their bodies and reproduce their populations. PSYCHOLOGICAL NEEDS: A family is composed of humans as sentient beings, with a whole spectrum of psychological needs that must be satisfied, such as identity, love, affection, and avoidance of pain and stress. RESPONSIBILITY: A family and its individuals are conscious actors that are aware of consequences of their actions and cannot escape responsible choice.

*Basic orientors of systems*

Environment-determined:

EXISTENCE: The system must be compatible with and able to exist in the *normal environmental state*. The information, energy and material inputs necessary to sustain the system must be available.

EFFECTIVENESS: The system should on balance (over the long term) be effective (not necessarily efficient) in its efforts to secure *scarce resources* (information, matter, energy) and to exert influence on its environment.[28]

FREEDOM OF ACTION: The system must have the ability to cope in various ways with the challenges posed by *environmental variety*.

SECURITY: The system must be able to protect itself from the detrimental effects of *environmental variability*, i.e., variable, fluctuating and unpredictable conditions outside the normal environmental state.

ADAPTABILITY: The system should be able to learn, adapt and self-organize to generate more appropriate responses to challenges posed by *environmental change*.

COEXISTENCE: The system must be able to modify its behaviour to account for behaviour and interests (orientors) of *other* (actor) *systems* in its environment.[29]

System-determined:

REPRODUCTION: Self-reproducing (autopoietic) systems must be able to reproduce (either as individuals and/or as populations).

PSYCHOLOGICAL NEEDS: Sentient beings have psychological needs that must be satisfied.

RESPONSIBILITY: Conscious actors are responsible for their actions and must comply with a normative reference.

This example shows that system orientors can be used as a handy checklist of what is important in and for systems, i.e., the basic system needs. In discussing sustainable development, this checklist of basic orientors can be used to find indicators for the viability of the different systems (see Sec. 5.3).

### *Orientors as normative guidelines; finding indicators of orientor satisfaction*

We use the term orientor as a general term to denote such orientations, interests or guidelines. In the human context, orientors are normative objects like values, norms, goals and objectives. The different orientors are essentially reminders on a checklist to which a viable system would (consciously or automatically) have to pay at least a minimum of attention.

Basic orientors represent the most fundamental aspects of systems orientation. The basic orientors resulting from the fundamental environmental properties are identical across all self-organizing systems, irrespective of their functional type or physical nature. In a particular application, this general checklist of basic orientors must be made system and context specific. We must say what we specifically mean, for example, by freedom of action of a commercial enterprise. This will normally lead to a more concrete subset of orientors (such as freedom from government interference, independence from suppliers, innovative potential, and so on) and perhaps a whole hierarchy of orientors.[30]

To assess the viability of a system, indicators must be defined that provide information about the state of basic orientor satisfaction. This is not possible at the level of the basic orientors themselves: systems have no state variables such as freedom of action or security. Rather, the state of satisfaction of these basic orientors must be inferred from available state or rate variables, or their combinations. This often requires the specification of an orientor hierarchy with several layers of orientors to convert the information from a specific indicator into information about corresponding basic orientor satisfaction.

### *Basic orientors are unique: one orientor cannot substitute for another*

Our objective is to develop a general method for finding a comprehensive set of indicators of sustainable development, i.e., a set of indicators that captures all essential aspects of system viability. The basic orientors are to serve as a checklist to make sure that essential aspects of viability and sustainability are not overlooked.

Because it is better adapted to the different aspects of its environment, the system equipped for securing better overall basic orientor satisfaction will have better fitness, and will, therefore, have a better chance for long-term survival and sustainability.[31] Assessment of orientor satisfaction provides an indication of system fitness in its environment, i.e., its viability and sustainability. The assessment of orientor satisfaction, i.e., of system viability, can be done by identifying indicators that can provide information about how well each of the orientors is being fulfilled at a given time.

But do the basic orientors cover all essential aspects? Second, are all the basic orientors required, or could we perhaps replace a particular orientor by one or a combination of other orientors?

These questions are important. If we have not captured all essential aspects, the picture will be incomplete—some vital dimension will be missing (assume, for example, that we forgot security). And if we are using too many dimensions (orientors), the assessment will be distorted because of double-counting (assume, for example, we had listed security and safety as two separate orientors). To use an analogy, we need a set of orientors that allows us to represent any picture in full colour by using the minimum set of primary colors (red, blue and yellow).

The evidence from much research[32] seems to be that the set of basic orientors is complete (covering all essential aspects), and that each basic orientor is unique (cannot be replaced by others). Everyday language seems to confirm this. We have names for everything that reality has taught us as being important, but there do not seem to be any major concerns of systems orientation that could not be represented by the basic orientors.

Each of the basic orientors is assumed to stand for a unique requirement. That means that a minimum of attention must be paid to each of them, and that compensation of deficits of one orientor by over-fulfillment of other basic orientors is not possible. For example, a deficit of FREEDOM OF ACTION in a society cannot be compensated by a surplus of SECURITY. Viability requires adequate satisfaction of *each* basic orientor.

Note that uniqueness of each of the basic orientor *dimensions* (categories) does not imply independence of individual basic orientor *satisfactions*. For example, better satisfaction of the SECURITY orientor may require a sacrifice in FREEDOM OF ACTION because financial resources are needed for the former, and are then unavailable for the latter. But that doesn't mean that freedom can be used as a substitute for security. Also, there may be synergistic effects, where improving satisfaction of one orientor may also improve satisfaction of another. For example, more efficient resource use (effectiveness) may lead to more freedom of action as resources are freed for other uses. That does not change the fact that EFFECTIVENESS and FREEDOM OF ACTION are entirely different categories of orientation.

### *The basic orientor currently 'in the minimum' is the limiting factor of system development*

Viability and sustainability of a system require adequate satisfaction of each of the system's basic orientors, just like plants need adequate supplies of each growth factor (light, water, nitrogen, phosphate, potassium, and so on).

Planning, decisions and actions in societal systems must, therefore, always reflect at least the handful of basic orientors (or derived criteria) simultaneously. Comprehensive assessments of system behaviour and development must hence be multi-criteria assessments. In analogy to Liebig's Principle of the Minimum, which states that plant growth may be constrained by a limiting factor (e.g., insufficient nitrogen or water), a system's development will be constrained by the basic orientor that is currently 'in the minimum.' Particular attention will have to focus on those orientors that are currently constraining.

In the orientation of system behaviour, we deal with a two-phase assessment process where each phase is different from the other.

*Phase 1:* First, a certain minimum satisfaction must be obtained separately for each of the basic orientors. A deficit in even one of the orientors threatens long-term survival of the whole system. The system will have to focus its attention on this deficit.

*Phase 2:* Only if the required minimum satisfaction of *all* basic orientors is guaranteed is it permissible to try to raise system satisfaction by improving satisfaction of *individual* orientors further—if conditions, in particular other systems, will allow this. However, there are upper limits to basic orientor satisfaction. For example, excessive emphasis on SECURITY or FREEDOM OF ACTION or ADAPTABILITY is obviously pathological and reduces viability and sustainability.

Viable systems, with adequate minimum satisfaction of all basic orientors, may differ in their basic orientor emphasis. Characteristic differences in the behaviour (life strategies) of organisms, or of humans or human systems (organizations, political or cultural groups) can often be explained by differences in the relative importance attached to different orientors (i.e., emphasis on FREEDOM, or SECURITY, or EFFECTIVENESS, or ADAPTABILITY) in Phase 2 (i.e., after minimum requirements for all basic orientors have been satisfied in Phase 1).[33]

## 3.4. Other evidence of basic orientors and their role

### *Evidence of basic orientors is found in many fields of science*

The emergence of basic orientors in response to the general properties of environments can be deduced from systems theoretical arguments, as has been done here, but supporting empirical evidence and related theoretical concepts can also be found in such fields as ecology, psychology, sociology, religion, and the study of artificial life.

If basic orientors are indeed the consequence of adaptation to general environmental properties, and, therefore, of fundamental importance to the viability of individuals, then we can expect them to be reflected in our emotions. This is indeed the case.[34] Each of the basic orientor has a characteristic counterpart in our emotions.

Also, we find that all societies have developed methods of punishment by selective basic orientor deprivation.[35] The spectrum of punishment applied by most societies is an indirect confirmation of the importance of the basic orientor dimensions to human life and well-being: depending on kind and severity of the offence, the delinquent is denied full satisfaction of one of the basic orientors—society takes away what is most valuable to the individual.

Perhaps the most vivid and striking description of basic orientors and the consequences of removal of orientor satisfaction for the individual and society is found in the Bible (Deuteronomy, the fifth book of Moses) 28, verse 1–69).[36] In the final section of the explication of Mosaic laws, very explicit blessings and curses are formulated for those that either uphold or violate the laws. They deal with EXISTENCE (22, 27, 48, 53-57), EFFECTIVENESS (23, 28f, 30, 32, 38), FREEDOM OF ACTION (41, 43f, 48), SECURITY (52, 65-67), ADAPTABILITY (22, 24, 27, 35, 44, 48, 51, 59, 61), and COEXISTENCE (26, 29, 37, 38f, 42, 43f, 53-57).

The empirical results of psychologists like Cantril, Maslow and Rokeach[37] can easily be brought into agreement with the orientation theoretic framework used here.[38] In his work on human scale development, Manfred A. Max-Neef has classified human needs according to several categories that can be mapped onto the seven basic orientors[39] (Table 1). The coincidence of these two independently developed lists is striking, but some remarks are in order. As explained above, the first six entries are basic system needs that apply to any self-organizing system, human or not. It comes as no surprise that they also appear as basic human needs. Since they are manifest in corresponding emotions, they can be interpreted as psychological needs, although their origin is of a general system nature. However, the items affection and identity in Max-Neef's list are truly psychological needs; they cannot be explained by system requirements alone. Why are understanding and leisure juxtaposed with the effectiveness orientor? Effectiveness is obviously a function of knowledge and understanding. But effectiveness is also a function of rest, contemplation and creative idleness.

Cultural theory[40] identifies five types of individuals in the social world, each having characteristic and distinct value orientation and lifestyle: egalitarians, hierarchists, individualists, fatalists and hermits. Orientation theory explains these different lifestyles in terms of different basic orientor emphasis, and furthermore fills two obvious gaps in cultural theory: innovators and organizers (Table 1). The egalitarian stresses partnership in

COEXISTENCE with others, the hierarchist tries to gain SECURITY by regulation and institutionalized authority, the individualist tries to keep his FREEDOM by staying free from control by others and the system, and the fatalist just tries to secure his EXISTENCE in whatever circumstances he finds himself in. The autonomous hermit, stressing his own PSYCHOLOGICAL NEEDS, is of no practical relevance to the social system. The innovator stresses the basic orientor ADAPTABILITY, while the organizer concentrates on EFFECTIVENESS.

***Table 1. Basic orientors reflected in psychological and social needs, lifestyles, social systems and ecosystems.***

| **basic orientors**<br><br>(Bossel 1977) | **psychological and social needs** (Max-Neef 1991) | **cultural theory lifestyle** (Thompson et al. 1990) | **social system concepts** (Luhmann, see Baraldi et al. 1997) | **ecosystem properties** (Müller and Fath 1998) |
|---|---|---|---|---|
| **existence** | subsistence | fatalist | environmental compatibility | (meta)stability, resilience |
| **effectiveness** | understanding, leisure | (organizer) | code, programs | cycling, loss reduction |
| **freedom of action** | freedom | individualist | variety | heterogeneity, diversity |
| **security** | protection | hierarchist | redundancy | redundancy, storage |
| **adaptability** | creation | (innovator) | autopoiesis | genetic diversity, patch dynamics |
| **coexistence** | participation | egalitarian | double contingency | landscape gradients, ecotone structures |
| **psychological needs** | affection, identity | hermit | reflection | |

Although Luhmann's theory of social systems[41] concentrates on the cognitive and communicative processes of social systems while neglecting their material structure and state-determined dynamics, the basic orientor aspects can also be recognized in his theory (Table 1).

Müller and Fath have related general ecosystem properties to the basic orientors[42] (Table 1). These ecosystem properties can be understood as specific processes that emerged in ecosystems in the course of their coevolutionary development in response to basic orientor demands.

One can find solid evidence of the basic orientors even in computer experiments with 'animats' that simulate the evolution of intelligence in artificial life.[43] This artificial intelligence evolves differently in different animats, resulting in different lifestyles. The differences can be traced back to different emphases on the basic orientors (i.e., emphasis on FREEDOM, or SECURITY, or EFFECTIVENESS, or ADAPTABILITY). These value dimensions emerge in the animat's cognitive system as it gradually learns to cope with its environment. These experiments in artificial life show that values are not subjective inventions of the human mind, but are basic system requirements emerging from a system's interaction with its environment.

This conclusion is also evident from Table 2, where the emergence of basic orientors is linked to qualitative jumps in system complexity (as discussed in Sec. 3.1).

In our search for indicators of sustainable development, we have to apply the basic orientor concepts to systems of the highest level of complexity: natural systems and human systems. This means that for assessment of their viability and that of their diverse subsystems, the indicators selected have to represent the full list of basic orientors, with RESPONSIBILITY only for systems with human actors. However, in all of the following, the REPRODUCTION aspect will be subsumed under the EXISTENCE orientor, while the RESPONSIBILITY orientor is reflected in the selection of the horizon of responsibility (see below), i.e., in the selection of present and future systems for whose development responsibility is assumed. This leaves the seven basic orientors: EXISTENCE, EFFECTIVENESS, FREEDOM OF ACTION, SECURITY, ADAPTABILITY, COEXISTENCE, and PSYCHOLOGICAL NEEDS.

***Table 2. Relationship between environmental properties, system complexity and basic orientor emergence.***

| **environmental property** | **system category** | **additional basic orientor** |
|---|---|---|
| | | *environment-determined:* |
| normal environmental state | static; metabolic | **existence** |
| resource scarcity | self-supporting | **effectiveness** |
| variety | selective | **freedom of action** |
| variability | protective | **security** |
| change | self-organizing | **adaptability** |
| other systems | non-isolated | **coexistence** |
| | | *system-determined:* |
| | self-reproducing | **reproduction** |
| | sentient | **psychological needs** |
| | conscious | **responsibility** |

# 4. What indicators to select? Unavoidable choice

## 4.1. The general scheme: basic orientors provide a checklist

*Illustrative examples*

If we went through the list of basic orientors before embarking on a journey in an unknown car,

- the EXISTENCE orientor would remind us to check the car's structural integrity and reliability,
- the EFFECTIVENESS orientor would have us check steering and fuel consumption,
- the FREEDOM OF ACTION orientor would let us make sure that we have enough fuel, and that the fuel indicator works,
- the SECURITY orientor would have us check brakes, oil-level and seat belts,
- the ADAPTABILITY orientor would make us test the heater, roll the windows up and down, try the seat adjustment, and check the spare tire and tools,
- the COEXISTENCE orientor would cause us to check headlights, brake lights and turn indicator lights, and
- the PSYCHOLOGICAL NEEDS orientor would let us choose a make and model agreeing with our personal taste and perhaps social status.

Viability of a system requires that an essential minimum of satisfaction of each of the basic orientors must be assured. This leads to specific questions for which we have to provide answers by finding and observing appropriate indicators. In this way we arrive at the general scheme used in this report for defining indicator sets. Table 3 illustrates how the list of basic orientors can be used for finding indicators of viability for a family.

*Application to sustainable development*

Attention to all basic orientors of *all* the different subsystems *and* the total system would guide us in finding reliable indicators and making sensible decisions with respect to sustainable development of human society. However, the total system of sustainable development is more complex than a family. It can be thought of as being composed of several major subsystems (for example, the human, support and natural systems defined in Sec. 2.3), each of which can be viewed as an assemblage of linked and nested subsystems composed of sub-subsystems, and so on. Moreover, all of these systems produce their own intrinsic dynamics with characteristic time scales. Most of the systems are complex, adaptive, and self-organizing, changing their structure and behaviour in the course of time. Some of the subsystems play a crucial role for the viability of the total systems; their viability requires particular attention.

These facts must be considered when defining indicator sets. The present section deals with the difficult problem of finding representative indicators, i.e., as few as possible, but as many as necessary.

***Table 3. Finding indicators for the viability of a family.***

| **orientor** | **system performance** | **possible indicators** |
|---|---|---|
| **existence** | Is the system compatible with and able to exist in its particular environment? | availability of shelter, clothing, food, water, sanitation, life expectancy |
| **effectiveness** | Is it effective and efficient? | work hours necessary for life support, efficiency of resource use |
| **freedom of action** | Does it have the necessary freedom to respond and react as needed? | income level, job opportunities, health, mobility |
| **security** | Is it secure, safe and stable? | safe neighbourhood, savings, insurance, social security scheme |
| **adaptability** | Can it adapt to new challenges? | education and training, flexibility, cultural norms |
| **coexistence** | Is it compatible with interacting subsystems? | social skills, compatibility of language and culture |
| **psychological needs** | Is it compatible with psychological needs and culture? | emotional stress, anxiety, dissatisfaction, family quarrels |

## 4.2. Indicators for dynamic systems in a dynamic environment

### *Rates of change, intrinsic dynamics and system pace depend on system structure*

The major reason for the search for indicators is the wish to receive timely warning of changes that are developing in the system to allow prompt control and counteraction, if that should be necessary.

The systems for which we seek to find indicators are all dynamic: populations and economies grow or shrink, pollution accumulates or is absorbed, resources are being depleted. Sustainable development in itself implies continuing but unpredictable change—sometimes slow, sometimes fast. Change here means change of system states (like population, pollution level or food stocks). The rates of change provide the most important information about changes in a system, and they are important candidates for indicators. (This basic fact is also underscored by the mathematical way of describing dynamic systems using a set of differential equations, which are specifications of the rates of change in a system.)

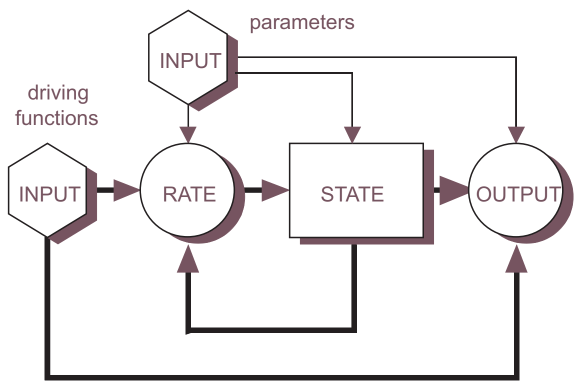


*Fig. 6. General system structure of dynamic systems. System behaviour (observable as output) is only partly directly related to input (outer loop). The characteristic dynamics of the system are caused by the inner feedback loop (rate–state–rate).*

The rates of change of the state variables and their interacting effects on the system states determine the dynamic characteristics of a system (Fig. 6). System dynamics are only partly a consequence of inputs from the system environment. Very often, the dynamic behaviour is overwhelmingly determined by the internal structure and processes of the system and can hardly be influenced from the outside. The interactions within the system, in particular possible feedback loops in the system structure, cause intrinsic dynamics (eigendynamics) that are characteristic for the system, and that may be much stronger than external influences. These intrinsic dynamics have time constants (i.e., delay times) and natural frequencies that are characteristic for the system. These time constants and characteristic frequencies must be respected in dealing with the system; they determine the pace of system response.

Because dynamic processes operate largely at their own pace, they will resist attempts to force them to respond in ways that do not agree with their characteristic time constants and frequencies. We are familiar with this phenomenon: pushing a swing at the wrong time will stop it; pushing it at the right time will make it fly higher. The complex systems involved in sustainable development show the same general characteristic. The indicators we choose should be compatible with this pace of the system to provide us with timely information about its dynamics.

### *Delays, early warning and the role of models*

The intrinsic system dynamics are directly related to system viability. If destructive processes in the system or its environment can build up at a faster rate than countermeasures can be taken by the system or its managers, its existence is at stake. If its processes of learning and adaptation are slower than the pace of environmental changes, then its adaptability is inadequate for ensuring long-term viability, i.e., sustainability.

The fact that system states can only change gradually means that in real systems the response to even a strong interaction will always be delayed. For example, it will take years before significant impacts of birth control or pollution control become apparent. Because of the often long delays before an undesirable or dangerous development becomes obvious through changing system states, it is essential to look for indicators that provide an early warning. For this reason it makes sense to prefer indicators that show *impending* change, i.e., rate variables, over those that only register change when it has been completed, i.e., state variables.

For sustainability, reactive control may come too late; proactive (anticipatory) control is often needed. It may not be enough to wait until a crucial variable actually changes (feedback control), but it may be necessary to *anticipate* that change before it happens (feedforward control). Anticipation requires having a dynamic model that can reliably predict what is going to happen next.

Flood control illustrates the crucial difference between feedback and feedforward indicators. Feedback means waiting until people start complaining of water in their living rooms, before doing something when it would be too late anyway. Feedforward means monitoring rainfall and water levels in the upstream watershed and starting flood prevention measures before a flood develops, using a mental or computer model based on experience.

In view of the dynamics of real systems, it is essential to focus on indicators that provide early warning of impending threats, leaving enough time for adequate response. This requires having reasonably good understanding of the systems involved, i.e., adequate models (mental, mathematical or computer models) of system structure and dynamic behaviour under different conditions.

## 4.3. Is there enough time for corrections? Defining Biesiot indicators

### *Response time and respite time*

For assessing sustainable development, we have to be concerned with the viability of the different essential systems and their contribution to the viability of the total system. In particular we have to determine whether the viability of the different systems is improving or deteriorating. This requires concentrating on indicators that relate the rates of change of threats to the satisfaction of the different basic orientors to the rates of evasive system response, or the *respite time* to the *response time*.[44]

To stay viable and sustainable, a system must be able to respond or adapt to threats before they get a chance to do serious damage. In other words, there must be enough time (respite time) for an effective response. The time it takes to get an effective response under way (response time) must be less than the respite time. The concept of respite time originated in nuclear technology.[45] Respite time, also called walk-away time, is the length of time a nuclear reactor can be left unattended. In current reactors, this is only a few seconds: the Chernobyl nuclear accident was a result of the respite time being much shorter than the response time.

The respite time concept is important for societal development as well. There are some destructive developments that do not leave enough time for countermeasures once the process has started. There are two possibilities: (1) the respite time of such processes must be lengthened, i.e., they must be slowed down, and/or (2) the response time of the system and/or its managers must be shortened. Coping successfully with these possibilities calls for early and accurate signals, i.e., proper indicators of the rate of threats and of the possible speed of response. This information can be combined in one indicator, a non-dimensional Biesiot indicator, by taking the ratio of the two rates.

Response time is the inverse of the rate of response: if the rate of response is high, the response time will be short. Since it is usually rates of change that are available as indicators, it makes sense to relate a rate of response to the threatening rate of change in the system or its environment to which the system has to respond in order to remain sustainable. If this ratio is greater or equal to one, the system will stay ahead of the challenge; if it is less than one, its viability is being eroded, and its eventual survival is at stake. It's a simple, everyday concept: if the rabbit outruns (response) the pursuing fox (threat), it will be safe; if not, it will be eaten.

### *Biesiot indicators for threats to basic orientors*

Sustainable development implies environmental change because of the coevolution of human and natural systems. Changes in the human system, and changes imposed on it by its environmental system, must be slower than corresponding adaptation processes in the human system and the natural processes on which it depends. It is, therefore, important to identify indicators that provide timely information about crucial changes of the human system and its environment and to relate this information to the possible rate of response with respect to each of the basic orientor categories.

We have to apply this idea to each of the basic orientors of a given system: we know that if one of them is threatened, viability will be at stake. Hence, we must define indicators that give as a clear picture of the ratio of system response rate to orientor erosion rate.

- EXISTENCE. Is the speed of escape from an existential danger greater than the speed of its approach? Example: Does the rate of increase of grain production stay ahead of the rate of increase of grain demand of a growing population?
- EFFECTIVENESS. Is the rate of increase in resource use efficiency (matter, energy, information) greater than the rate of erosion of resource availability? Example: Can the rate of water use reduction due to advances in irrigation technology offset the rate of groundwater depletion?
- FREEDOM OF ACTION. Is the rate of increase in the spectrum of possible responses (system variety) greater that the rate of appearance of new challenges (environmental variety)? Example: Are new concepts introduced into educational curricula at a sufficient rate to keep up with the rate of increase of diversity and variety in society and technology?
- SECURITY. Does the rate of installation of protective measures keep up with the rate of increase of threats? Example: Are dikes thrown up quickly enough to stop a rising flood?

- ADAPTABILITY. Does the rate of structural change in the system keep up with the rate of irreversible changes in the environment? Example: Can the rate of creation of new jobs in new industries keep up with the rate of jobs lost to productivity increases?
- COEXISTENCE. Can the rate of change in interaction and communication keep up with the rate of appearance of new actors? Example: Can the perceptions and prejudices in a community change quickly enough to cope with the rate of influx of foreign immigrants?
- PSYCHOLOGICAL NEEDS. Does the rate of appearance of psychological stresses and strains remain below the rate at which they can be absorbed? Example: Do insults, injuries and injustices to children in a particular society cause permanent psychological damage?

*Quantification with Biesiot indicators and visualization of the state of viability*

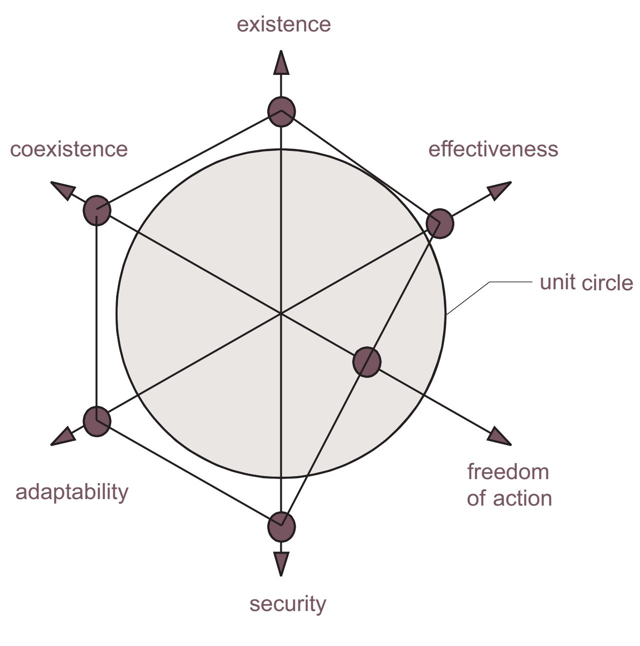


*Fig. 7. Orientor star using Biesiot indicators: the system is not viable if any of the orientor satisfactions, expressed by the ratio of rate of response to rate of threat, has a value of less than one, i.e., is inside the unit circle.*

A Biesiot indicator is defined as the ratio of two particular time rates of change of a given quantity: its rate of restoration (or response) and its rate of deterioration (or threat). It can also be defined by the inverse of the two rates, i.e., the time constants of respective processes (respite time vs. response time). The Biesiot ratio is nondimensional; it has the value of unity if both rates are equal. The value one, therefore, marks the critical point: if the rate of response is greater than the rate of threat, the system can handle the particular threat; if it is smaller, system viability is threatened.

If Biesiot ratios are used to express basic orientor satisfactions of a system, the corresponding indicators provide a direct measure of viability: viability (and hence sustainability) is threatened if any of the indicators falls below a value of one. The viability state of a system becomes immediately obvious if the values of the respective Biesiot indicators are plotted on the rays of an orientor star (Fig. 7).

## 4.4. The cyclical nature of system evolution and indicators of sustainability

### *Growth and decay in real systems*

The processes of self-organization that continuously change the complex systems in the real world often exhibit their own cyclical dynamics. These development cycles have some relevance for the selection of indicators, since the focus of attention will necessarily shift during the cycle.

Four distinct stages can be identified:[46] (1) renewal and growth, (2) conservation, (3) deterioration and creative destruction, and (4) innovation and reorganization. The cycle then repeats. This sequence can be observed in industrial and urban development as well as in the gap dynamics of natural forests, and in many other processes of evolutionary self-organization. It can be expected to also play a role in the sustainable development of societies, and the selection of indicators should take account of it.

The penetration of new technologies, the renewal of infrastructure and production capital, changes in work and employment, changes in the age composition with their implications for infrastructure and social and cultural changes all drive this cycle. In fact, in a process of entrainment (mode-locking), the different processes are likely to reinforce each other, leading to a synergetic process of cyclical self-organization.[47]

The cyclical process of renewal is not a circle leading back to the same conditions, but rather a spiral leading to a new evolutionary plateau after each cycle, with a different system structure from before. During the dynamic periods of innovation and reorganization, renewal and growth, new structures are built up.

Growth then stagnates, and the existing structures serve and support the system during a lengthy period of conservation, before they begin to deteriorate and are finally destroyed to make room again for innovation and reorganization.

### *Indicator emphasis changes during the development cycle*

The different phases of this cyclical process of evolutionary renewal favour or even require different basic orientor emphasis (life strategies) of the actors in this process. As noted before (Sec. 3.4), these life strategies can be related to the life styles of cultural theory.[48]

- The *renewal and growth* phase requires an emphasis on EFFECTIVENESS and FREEDOM OF ACTION, corresponding to the *organizer* and the *individualist* life strategies.
- The *conservation phase* requires an emphasis on SECURITY, corresponding to the *hierarchist* life strategy.
- The *deterioration phase* requires an emphasis on EXISTENCE, and perhaps COEXISTENCE, corresponding to the *fatalist* and the *egalitarian* life strategy.
- The *innovation phase* requires an emphasis on ADAPTABILITY, corresponding to the *innovator* strategy.

Note that in all phases all life strategies (cultural types) will be present, but different strategies are likely to dominate in the different phases.

An actor with a life strategy emphasizing FREEDOM OF ACTION is likely to also stress corresponding indicators. The same is true for all other life strategies. We can expect that in the different phases of the development cycle, the emphasis on indicators is likely to shift from EFFECTIVENESS and FREEDOM OF ACTION in Phase 1, to SECURITY in Phase 2, to EXISTENCE and COEXISTENCE in Phase 3, to ADAPTABILITY in Phase 4. This is acceptable as long as the indicator set remains complete, i.e., covers all aspects of viability (the basic orientor dimensions) adequately.

### *The need for flexibility and periodic revision of indicator sets*

As systems change and develop in a changing environment, individual indicators may lose their relevance and may have to be replaced by others that are more relevant under current conditions. Where once coal consumption per capita may have been a useful indicator of living standard, the number of computer chips in use per person may be a better indicator at another time. Social and technological change require periodic reassessment and revision of the indicator set. Occasionally, this may not be enough: there may be a qualitative change of conditions leading to a completely new threat that requires its own indicators. It is important to maintain flexibility and the ability to revise the indicator set quickly in response to new challenges.

## 4.5. The horizon of attention

### *Essential systems and multidimensional viability: the need for many indicators*

The systems aspect of sustainable development implies concern about a total system composed of the many natural and human subsystems, while the long-term aspect of sustainable development implies concern even about the future of these systems. Obviously it is a practical impossibility to develop and use an indicator set that includes indicators of viability from every system in the total system.

Realizing that a drastic restriction to a manageable number of indicators is essential, we face the difficult task of defining a set of indicators that can provide a picture of the viability and sustainability of the total system and essential subsystems. We found earlier that the hope for a single index of sustainability is futile and that a system-oriented approach is needed to define a minimum set of representative indicators.

We concluded earlier that, as a minimum, the viability of three essential systems would have to be considered: the human system, the support system, and the natural system (representing human, built, and natural capital; see Sec. 2.3). Furthermore, their individual contribution to the viability of the total system has to be assessed.

We also found that viability of a system is a multidimensional concern and can only be assessed by determining the state of satisfaction of each of the seven basic orientors. A full sustainability assessment, therefore, requires a minimum of 3x2x7 or 42 representative indicators.

### *Looking for the weakest links*

As large as this number may seem, it still means that a single indicator would, for example, represent the SECURITY of all of the natural system. This may seem preposterous, but it cannot be an argument for rejecting the method: this would only throw us back to indicator systems that are either *ad hoc* or have other serious systematic deficiencies (see Sec. 2.2). It would be an argument for using a finer-grained representation of the systems involved and of basic orientor satisfactions (e.g., by a detailed orientor hierarchy, see Sec. 5.3), but this would increase the number of indicators again.

The practical solution to this dilemma is to define indicators that represent the weakest links (component systems) in the total system. Viability depends on balanced minimum basic orientor satisfaction, and it is the orientor deficits that threaten sustainability. Hence, we must focus on those component systems that show such deficits. But since a present deficit, caused by one component system, may eventually disappear and be replaced by another, caused by another component system, it will then be essential to periodically review and redefine the set of indicators.

The selection of indicators is contingent on having a fair amount of information about a system. Variables that could be used as indicators must not only be recognized, but also known for what role they play in the system, how essential they are for the viability of the system, or whether they represent a weak link. Defining indicators of viability, therefore, requires at least a good conceptual if not formalized and/or computerized model of the system.

### *Comparable results of sustainability assessments despite subjective choice*

Even with a solid scientific approach, based on physical facts as well as systems theory and analysis, indicator sets cannot be defined without a significant amount of subjective choice. We should not be surprised if researchers using the same data and scientific method produce different indicator sets. Although this may superficially appear as another of those cases where scientists cannot agree, these indicator sets are far from arbitrary selections. If indicators have been selected to represent basic orientor satisfactions of essential systems, it is likely that sustainability assessments will produce comparable results, even if the indicator sets are completely different.

It is useful to recall where subjective choice is inevitable in the process of determining an indicator set:

- ***Knowledge about and perception of the total system.*** What is our model of the total system? What is the organization and interconnection of subsystems?
- ***Perception of subsystems and their interrelationships.*** What are the parts and processes of subsystems? How do they interact?
- ***Scenarios of future developments.*** Which developments are possible; which are likely?
- ***Time horizon.*** How far should we try to look ahead?
- ***Systemic horizon.*** Should only essential systems be observed, or should nonessential systems be included, like rare species without economic value?
- ***Interests of the observer/manager.*** What information is of interest for various reasons? What information is needed for management?

Obviously, even small disagreements between researchers with respect to each of these aspects can cause great variations in indicator sets. If researchers agree on a common goal of identifying indicators of sustainable development, the choice will be narrowed down somewhat, but very substantial variability still remains.

## *The horizon of attention defines indicator selection*

Although the normative reference (ethical framework) of the human actor (individual, organization and society) can have a substantial influence on indicator selection, its influence is not clear-cut. To discuss this effect, it is useful to distinguish between the actor's horizon of influence, horizon of attention and horizon of responsibility (Fig. 8).[49]

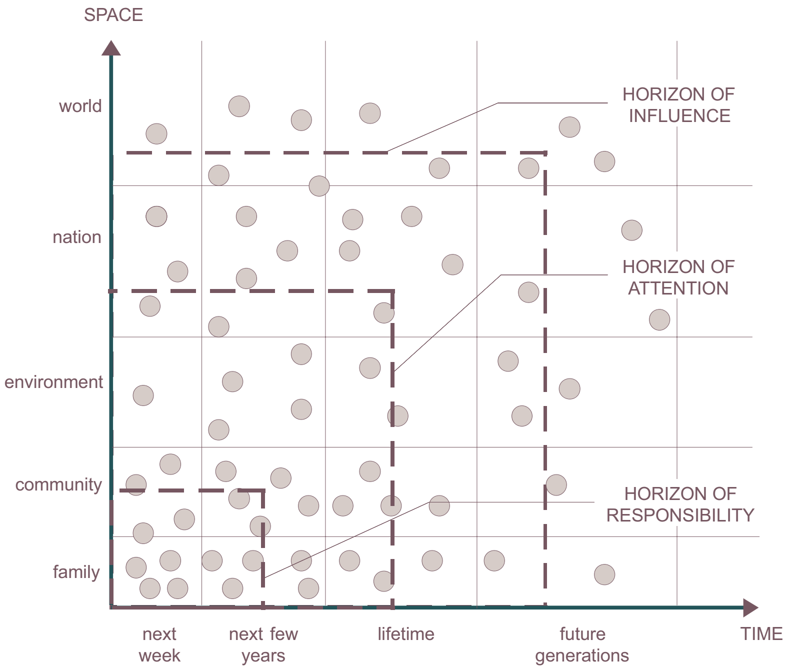


*Fig. 8. The horizons of influence, attention and responsibility in space and time (after Meadows et al., 1972). The dots indicate the distance in space and time of different human concerns.*

The *horizon of influence* stretches over all systems in space and time that are significantly affected by the actor's actions. The horizon of influence is a factual consequence of the relationships in the real system and the power of the actor. Given these facts, the actor cannot define his horizon of influence at will.

The *horizon of attention* comprises all systems whose behaviour or development is of some interest to the actor, and whose fate is given some attention by the actor. The horizon of attention is defined by the curiosity of the actor. It does not imply any commitment on his part for any of the systems within the horizon of attention.

The *horizon of responsibility* is limited to those systems for whose interests the observer would actually give up advantages (time, resources) or suffer inconveniences, i.e., for whose fate he would take some responsibility. The horizon of responsibility is defined by ethical considerations of the actor. It implies non-zero commitment to the fate of systems within the horizon of responsibility.

The horizon of attention, i.e., the indicators observed, may actually be identical for actors with very different ethics, perhaps because their factual knowledge about the real world agrees. The actor's ethics do not necessarily determine the spectrum of indicators selected. However, the horizon of responsibility is certainly a product of the normative reference, and will have a substantial influence on how individual indicators affect decisions.

For example, a selfish but very clever actor would probably attempt to collect as much information about his or her environment as possible (wide horizon of attention), in the hope that even some of the seemingly irrelevant indicators might provide clues of impending developments that could be used to advantage. His horizon of attention could be even wider than that of an altruist carefully observing indicators of the many systems he feels he has to be concerned about. However, the horizon of responsibility of the selfish actor would be essentially limited to himself or herself.

Ideally, the horizon of responsibility would coincide with the horizon of influence, while the horizon of attention would be at least as wide as the horizon of responsibility.

### *Indicator selection can be independent of ideology*

We conclude from this that ideological differences, fortunately, must not stand in the way of agreeing to a common comprehensive set of indicators of sustainable development. The choice of horizon of attention, i.e., the indicators set, is independent of a particular ethical commitment. If one group insists on adding a particular indicator, this will be merely a piece of additional information that cannot hurt the other group. In fact, the process of indicator selection will be much more effective if representatives of different interests participate in it. This is no licence for endless inflation of the indicator set: all participants should still honour the goal of parsimony, obtaining the maximum amount of information from the smallest possible set of indicators.

Normative differences, however, definitely determine the horizon of responsibility and play a major role in determining decisions based on indicator information, i.e., how much importance is attached to this or that indicator of this or that system.

## 4.6. The horizon of responsibility

### *The decision for sustainable development defines a horizon of responsibility*

There is an important relationship between the horizon of attention and the horizon of responsibility: responsible action requires that the horizon of attention must be at least as large as the horizon of responsibility, but it must not be smaller. There is no harm in knowing more about the world than we are responsible for, but knowing less would be clearly irresponsible, equivalent to driving at high speed in a fog.

The decision for sustainable development implies assuming responsibility for long-term development of human and natural systems inasmuch as it is significantly influenced by us. That automatically expands the necessary horizon of attention to a significant number of interconnected systems, and far into the future. But even genuinely sustainable development can come in different forms and shapes, as we have seen earlier (see Sec. 1.1). The spectrum reaches from just maintaining minimum viability and sustainability levels of man and beast to development at a maximum level of diversity and coevolutionary potential of human society and natural environment.

On top of a minimum set of indicators mandated by the decision for sustainable development, the decision for a particular type of sustainable development, therefore, requires additional indicators that capture concerns reaching beyond the bare minimum of human sustainability. The type of sustainable development chosen reflects a particular ethical principle or normative reference: do we want a sustainable world serving the economic interests, selfishness and greed of transnational corporations and their shareholders, or are we aiming for a world sustaining maximum evolutionary potential by respecting the interests of all beings? Each choice implies a different horizon of responsibility, hence a different horizon of attention, and hence a different set of indicators.

### *Ethical choice is unavoidable*

In a world of limited resources (energy, materials, water, food and time), systems (such as organisms and species) often compete for resources, advantages and even survival. Even more dramatic, they may have no choice but to destroy other systems or organisms in order to survive, as in grazing or predator-prey food chains.

Even with the best of intentions, humans cannot be exempt from this fact of life. But being conscious beings, we have knowledge of what we are doing, we can visualize its implications for other beings and systems, we usually have the choice between different possible actions, and we are responsible for our actions. In other words, we cannot escape an ethical choice about our horizon of responsibility, and we have to adopt an ethical framework for our actions. This has direct consequences for the indicator set we are looking for: it has to include indicators at least for the systems within our horizon of self-assumed responsibility. If it has additional indicators for the larger horizon of attention, so much the better.

Ethics is essentially about how much relative importance we assign to ourselves, other human or non-human beings, ecosystems and future generations. That may reach from pure selfishness to an all-inclusive altruism. However, the decision for sustainable development narrows the choice of ethical reference considerably. The necessary concern for future generations and for the natural environment on which human society depends, for example, is not compatible with unrestrained selfishness or anthropocentrism.

It is impossible to prove a right system of ethics, as philosophers have concluded again and again over past millennia until today.[50] But it may be prudent to adopt a particular set of ethics for practical reasons.

This particular discussion is outside the scope of this report. However, a discussion of the implications of ethical choice for the selection of indicators will be helpful for defining an indicator set. Adopting the indicator set consistent with the horizon of responsibility of a particular ethic does not mean adopting that particular ethic; it merely means adopting the corresponding horizon of attention.

## 4.7. Arguments for a wide horizon of responsibility

### *Different ethical principles have different consequences for sustainability*

Sustainable development of human society is possible only with substantial support from the natural system. Hence, a minimum set of indicators from that system would be required to assess the sustainability of its processes. If such a society would merely focus on the material well-being of humans, its horizon of responsibility would only include those components of the natural environment that would provide material contributions to society: food, energy, materials and waste disposal. There would be no logical reason to feel responsible for the fate of species having no perceivable economic value, or to protect unique landscapes or ecosystems, or to expend resources on protection of social and cultural achievements. Such a society would have a limited set of indicators, but it could be physically sustainable.

The problem is that such a society would be operating at the edge of sustainability: a small change in its natural environment or an internal change in society could lead to collapse because diversity, variety and redundancy of the human and natural systems have been minimized in favour of material well-being. The potential to cope adaptively with unforeseen changes may be insufficient. If only indicators corresponding to the horizon of responsibility of this particular ethical framework were adopted, society would not be able to monitor all the information that may be decisive for the sustainability of its development.

### *Protecting evolutionary potential by a wide horizon of responsibility*

Sustainable development as a process of coevolution of human and natural systems under constantly changing conditions suggests a wider view. In fact, there are good reasons for adopting the widest possible view, i.e., horizon of attention, by protecting and encouraging as much variety, diversity and redundancy as possible, irrespective of its current usefulness. These are the factors that guarantee the widest possible spectrum of adaptive coevolutionary potential of systems even under severe change of conditions, i.e., a maximum amount of sustainability. In essence this boils down to conceding that human understanding and prevision of such coevolutionary developments in human and natural systems will always be incomplete and insufficient, and that it would be prudent to keep a maximum number of options open by respecting the viability interests of all living and non-living, present and future systems and beings, irrespective of their current usefulness for humans. Such a view is held by a partnership ethic.

### *Using the Principle of Partnership to guide indicator selection*

In a *partnership ethic*, ethical considerations are extended to all present and future component systems of the total system, human or non-human, living or non-living. The Principle of Partnership[51] states that *"All systems that are sufficiently unique and irreplaceable have an equal right to present and future existence and development."*

The principle protects individual conscious beings, species, singular ecosystems, original works of art or cultural achievements for their uniqueness, but not, for example, the individual mosquito or chicken. A similar principle of respect for system interests has been formulated by Johnson:[52] "Give *due* respect to all the interests of all beings that have interests, in proportion to their interests." A system is said to have interests if it can be observed to express preferences; e.g., a plant growing toward light. An ethic based on the sustainability postulate and the partnership principle implies the following in particular:

1. With respect to the natural environment, it means acknowledging species and ecosystems as systems having their own identity and right to existence, in the present and in the future. The natural environment cannot be viewed as a supposedly infinite source of resources, but must be viewed as life space on which our existence depends, full of systems having interests for whose future we are responsible because of our influence on them.
2. With respect to human systems, it means respecting the right to equitable treatment for all living humans, without differentiation by region, religion, race, gender, political conviction, income, wealth or education.
3. With respect to future systems, it means respecting the right for existence and development of future generations, species and ecosystems.

### *Relationship between ethics and the systems view*

The Partnership Principle provides a sufficiently wide horizon of responsibility for maximum diversity and hence coevolutionary potential. Even if this principle is not adopted as an ethical guideline, it would be prudent to adopt its horizon of responsibility as a proper horizon of attention and to select indicators accordingly.

These insights have to guide our choice of indicator sets for sustainable development. In particular, they call for proper representation of the interests of all component systems. We have to at least try to assess their role and function in the total system, now and in the future. This is the task of systems analysis. We find an unexpected connection between ethics and the systems view in issues of sustainable development; namely,

1. If we start with a systems view, trying to identify the role of all component systems for the sustainable development of the total system, we shall find that ethical criteria must be developed and applied to protect the interests of the various component systems contributing to the total system.
2. If we start with the ethical choice for sustainable development and try to break it down into practical ethical criteria for decision-making, we shall find that we cannot accomplish this without fairly detailed systems studies that also take into account the dynamics of development.

# 5. Defining indicator sets: procedure

## 5.1. The procedure: a summary

This section deals with the practical procedure of finding appropriate indicators. Applications will be presented in Sec. 6. The procedure has several distinct aspects and are as follows:

- ***Conceptual understanding of the total system.*** We cannot hope to find indicators representing the viability of systems and subsystems unless we have at least a crude, but essentially realistic, understanding of the total system and know what to look for. This requires a conceptual understanding as—at least—a good mental model.
- ***Identifying representative indicators.*** We have to select a small number of representative indicators from a vast number of potential candidates in the system and its subsystems. This means concentrating on essential variables of those subsystems that are essential to viability of the total system, and/or aggregating information.
- ***Quantifying basic orientor satisfaction.*** We must arrive at statements about whether the viability of certain subsystems or the total system is threatened and, if so, how seriously. This requires translating indicator information into information about orientor satisfaction.
- ***Participative process.*** These three procedural steps require a large number of choices that necessarily reflect the knowledge and values of those who make them. It is essential to bring in a wide spectrum of knowledge, experience, mental models, and social and environmental concerns to ensure that a comprehensive indicator set is found for a given application.

## 5.2. Conceptual understanding of the total system

Full understanding of the total system is not possible, but that cannot be an excuse for not doing the best possible job of collecting information and piecing together a comprehensive conceptual or even formal model of the system, its components and their interactions. It is usually possible to capture essential processes and relationships even in crude models, and the model can always be improved as new knowledge is gained about the system. We need this information to determine which subsystems are of particular importance and where to look for indicator candidates. It was argued earlier (see Secs. 4.5–4.7) that the widest possible horizon of attention should be used to remain aware of the full spectrum of options for sustainable development.

This is an enormous task. We have to structure this complex of interacting systems to make it accessible for analysis. This is done by identifying individual systems and noting their mutual interactions and relationships to other systems, and to their subsystems and suprasystems (Fig. 9).

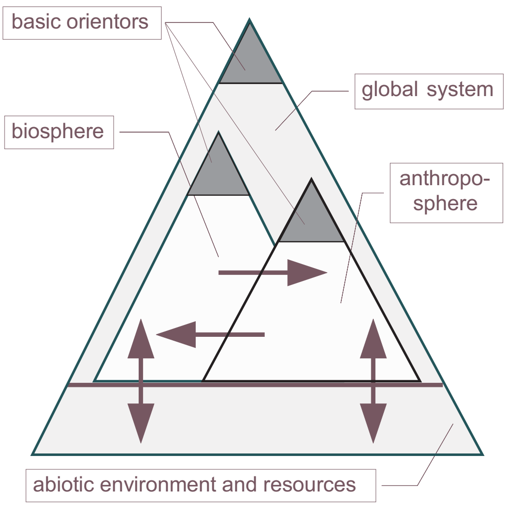


*Fig. 9. Mutual relationships of systems and their subsystems and suprasystems in the total system.*

We have to consider different kinds of relationships:

- All systems depend to some degree on the resource providing and waste absorbing capacities of their environment.
- Most systems have interactions with other systems that are essential to their viability.
- Many interactions are hierarchical, with subsystems contributing to the functioning of a system, which contributes to the functioning of a suprasystem, and so on.
- The viability of the total system depends on the viability of many but not necessarily all of its subsystems.

An understanding of important relationships between component systems is essential for the definition of indicators.

## 5.3. Identifying representative indicators

*Recursive scheme for finding indicators of viability*

In this systems view, the identification of indicators of sustainable development for the total or global system reduces to a recursive procedure, where the same questions have to be repeated for all component systems recognized as important or essential:

1. Which systems $y_i$, or environmental factors $e_i$, contribute to the viability of system x?
2. Which basic orientors of system x are affected by which system $y_i$?

In this way it is possible to first identify the major systems contributing to the viability of the total system, then the subsystems contributing to the viability of each major system, then the sub-subsystems contributing to the viability of each subsystem, and so on. In this top-down manner, the viability-affecting systems at all system levels, and their influences on the satisfaction of a particular basic orientor of an affected system, can be identified.

***Table 4. General (recursive) scheme for identifying indicators of viability.***

| basic orientor | viability of affecting system | contribution to affected system |
|---|---|---|
| **existence** | Is the system compatible with and can it exist in its particular environment? | Does the system contribute its part to the existence of the affected system? |
| **effectiveness** | Is it effective and efficient? | Does it contribute to the efficient and effective operation of the total system? |
| **freedom of action** | Does it have the necessary freedom to respond and react as needed? | Does it contribute to the freedom of action of the total system? |
| **security** | Is it secure, safe and stable? | Does it contribute to the security, safety and stability of the total system? |
| **adaptability** | Can it adapt to new challenges? | Does it contribute to the flexibility and adaptability of the total system? |
| **coexistence** | Is it compatible with interacting subsystems? | Does it contribute to the compatibility of the total system with its partner systems? |
| **psychological needs*** | Is it compatible with psychological needs and culture? | Does it contribute to the psychological well-being of people? |

** only for systems with sentient beings*

From this recursive procedure we can deduce a general bottom-up scheme of orientor assessment questions that have to be repeated for each pair of *affecting* system y and *affected* system x. Indicators are defined by two sets of questions: (1) What is the viability of the affecting system? (i.e., satisfaction of each basic orientor of that system), and (2) How does each affecting system contribute to the viability (the basic orientors) of the affected system? The general scheme of questions to which the indicator system must provide answers is given in Table 4.

### *Reducing the number of indicators to a manageable set*

It will be obvious that a detailed analysis following this scheme will usually produce a large number of component systems, long viability chains and many potential indicators. Furthermore, there will generally be several, perhaps many, appropriate indicators for answering each of the assessment questions or particular aspects of it. It is, therefore, essential to condense the systems analysis and the indicator set as much as permissible without losing essential information. There are several possibilities:

- ***Aggregation.*** Use the highest level of aggregation possible. For example, in the applications in Secs. 6.2 and 6.3, the total system is disaggregated to only three component systems: human, support and natural system.
- ***Condensation.*** Locate an appropriate indicator representing the ultimate cause of a particular viability problem, without bothering with indicators for intermediate systems (the intermediate viability chain). For example, using fossil fuel consumption as an indicator for threats to global climate and viability of the global system.
- ***Weakest-link approach.*** Identify the weakest links in the system and define appropriate indicators. Do not bother with other components that may be vital but pose no viability threats under foreseeable circumstances. For example, using availability of water in savanna agriculture as a weakest link, not nutrients, labour or farm machinery.
- ***Basket average.*** If several indicators representing somewhat different aspects of an orientor question should all be considered, define an index that provides an average reading of the situation. For example, using the representative basket of consumer goods for economic statistics.
- ***Basket minimum.*** If a particular orientor satisfaction depends on the acceptable state of each of several indicators, adopt the one with the currently worst performance as representative indicator.

*Note:* this means that a changing set of indicators will be used during system development. For example, using soil nutrient content represented by the nutrient being 'in the minimum' and, therefore, limiting soil productivity.

- ***Representative indicator.*** Identify a variable that provides a reliable information characteristic of a whole complex situation. For example, using the occurrence of lichen as indicator of air pollution. *Note:* when using a representative indicator, it is particularly important to state clearly what it is supposed to represent.
- ***Subjective viability assessment.*** If little quantitative information for a vital component system is available, use a summary subjective viability assessment. For example, usually it will be sufficient to assess the viability of a system by the subjective impression of health or lack of it of a component system, such as a person, animal, forest or company.

### Adding detail: orientor hierarchies

In some applications it may not be possible to provide a definite answer to a basic orientor question by reference to a single indicator. It may be necessary to employ several indicators to cover different aspects of the question (e.g., about SECURITY), and it may even be necessary to construct a hierarchy of orientors to correctly represent different aspects and to define corresponding indicators. The following scheme illustrates the approach for SECURITY at the national level using a three-level orientor hierarchy.[53] For each of the orientors and suborientors in this hierarchy, appropriate indicators would have to defined.

- SECURITY
  - SUPPLY SECURITY
    - DIVERSIFICATION OF INPUTS
    - CONSERVATION OF RESOURCES
  - NATIONAL SECURITY
    - INTERNATIONAL PEACE
    - MILITARY STRENGTH
  - RISK PROTECTION
    - SAFE LIVING CONDITIONS
    - SOCIAL SECURITY
    - LEGAL SECURITY
  - RESILIENCE
    - PERTURBATION SECURITY
    - SOLIDARITY
    - JUSTICE

### Systematic approach to asking the relevant questions

The systematic and theory-based feature of this method of determining indicators is important: we are not simply asking people to find and agree on a set of indicators; we are asking them to find answers (indicators) to very specific questions concerning *all the vital aspects of viability and sustainability*, i.e., the basic orientors. In this *structured approach*, based on systems theory and empirical evidence, we can be reasonably certain to obtain a *comprehensive set of indicators* covering all important aspects of systems viability and sustainability. The method avoids both unnecessary bunching of redundant indicators in some areas and creating gaping holes of oversight and neglect in others.

While it is advisable to choose indicators that allow unambiguous quantification, and hence comparison with conditions at other points in time or in other regions, this is not a necessity with the method proposed here. The important point is that the indicators chosen provide us with reliable answers to the different orientor assessment questions (Table 4). If satisfactory *qualitative* answers are obtained in *all* categories for all subsystems and the total system, we can conclude that the system is currently viable and sustainable. If just one of the categories is in an unsatisfactory state, a problem endangering viability and sustainable development is indicated.

### Other criteria for indicators of sustainable development

In addition to providing reliable answers to the respective orientor assessment question in Table 4, indicators must satisfy other criteria. Of particular relevance is attention to those Bellagio Principles (see Box, Bellagio Principles) that deal with openness of the definition and assessment process; effective communication to an audience, users and decision-makers; broad participation and representation of different groups; capacity for ongoing assessment in an adaptive process of learning and feedback, and providing institutional capacity and assigning responsibility for data support.

The indicators chosen should be readily available and unambiguous. Their meaning should be completely clear and understandable by all concerned groups, independent of their educational background. The data collection should not necessitate a complex, expensive and time-consuming effort. Ideally, it should be possible to gather the relevant information from simple observations of everyday life. Much relevant indicator information can come from data regularly collected and published by various organizations and by clever combination of such data to provide informative indicators.

## 5.4. Quantifying basic orientor satisfaction

### *Viability assessment may not have to be quantitative*

Assessments of viability and sustainability can be made at different levels of refinement: we can use the method for (1) quick and crude assessment, or for (2) detailed grading of orientor satisfaction, or for (3) computer-assisted assessments based on formal mathematical mapping functions (see Sec. 6.2).

The orientor assessment questions can often be adequately answered without an extensive database of numerical indicators by people with a good knowledge of the systems involved. In many applications it will not be necessary to wait until an expensive and time-consuming data collection effort gets under way. For a more systematic analysis and comparison of regional developments, numerical indicators would be required. If more detail is needed, several indicators may have to be defined for a particular category.

Note again that the different indicators cannot be combined into one number describing the current state of sustainability. The basic needs of systems, as represented by their basic orientors, are always multidimensional; each of the basic orientors has to be satisfied separately. It is not possible to trade or even compare, say, a lack of personal freedom with an overabundance of food.

It is possible to aggregate and simplify in another way: if *all* orientors are in a satisfactory state, i.e., if all interests of the system are adequately cared for, then we can simply state that the system is viable and, hence, sustainable. Here, we don't have to bother giving all the numerical details of the indicators we used to arrive at that conclusion. We may even have sufficient proof from other evidence that the system is viable without having to measure a set of indicators, much as a good doctor or farmer will be able to see how healthy a patient or a crop is.

Sustainability assessments often reduce to finding which of the affected systems are currently not viable, what the reasons are, and then finding solutions to the existing problems. In other words, we don't have to deal with the immense control panel of indicators all of the time, but only concentrate on the red lights.

### *Quantitative sustainability assessment*

Quantification of the sustainability assessment is necessary in particular for international comparisons and for analysis of development trends in time. If fully documented in all its steps, quantification can make results reproducible and analyzable.

Nevertheless, it should not be overlooked that quantitative assessments are still subject to the many subjective factors mentioned in Sec. 4.5, in particular the unavoidable subjectivity in the choice of indicators and assessment functions (see examples in Sec. 6.2). Quantitative sustainability assessments can be objective only within the limitations of the method and assumptions used.

Subjective bias in the actual viability assessment of a system is eliminated if Biesiot indicators can be used to quantify basic orientor satisfaction. These indicators consist of the ratio of a rate of system response to the rate of system threat, or respite time to response time, both with respect to a particular process (see Sec. 4.3). Both of these rates can in principle be quantitatively determined unambiguously by observing the system and its environment. The Biesiot ratio produces a very clear signal about viability. If the ratio is greater than or equal to one for a particular basic orientor, that orientor is not threatened. If it is less than one, the orientor and with it the viability of the system are at stake. If such indicators are plotted on the rays of an orientor star, the state of viability of a system becomes immediately obvious (see Fig. 7).

Data are often unavailable for defining Biesiot indicators. Here, the indicator states must be translated to corresponding orientor satisfaction states by using assessment functions. This mapping of indicator state on orientor satisfaction can only be produced by subjective assessment of the researcher. This quantification of the assessment function, however, is a vast improvement over a less formal subjective assessment, where the result varies with the person producing the assessment and his or her mood. It is, therefore, irreproducible. The quantitative assessment functions are open to discussion and change, can be entered into formal and computerized assessment, and can be applied to successive assessments to yield reproducible results. This approach is used for the formal sustainability assessment of the Worldwatch Institute time series in Sec. 6.2.

## 5.5. Participative process of indicator selection

### *Role of scientific method*

While systems theory can provide a systematic framework for guiding the search for indicators and assessing viability and sustainability, it cannot determine the final choice of indicators. This task remains to be completed by the investigators and it requires their subjective choice. The results will obviously be influenced by background, knowledge and experience of the investigators. It is, therefore, extremely important that people of different social and scientific backgrounds and political persuasion independently derive indicator sets by defining participating systems and use the scheme of orientor impact questions (Table 4). Initially, these indicator sets will differ, but experience shows that in intensive discussions with different points of view, the indicator lists will gradually converge.

Science cannot provide an objective method for finding the one-and-only true indicator set for a complex system. The reason is simple: the number of potential indicator candidates in such systems is very large, while the set of indicators must be relatively compact if it is to be of any value. Hence, there must be selection and aggregation. Moreover, there is always less than full knowledge about a system or problem, and there is no guarantee that all vital indicators are already in the list of candidates. Hence, there will usually also be a search process that may yield more candidates, but that still cannot guarantee identifying all vital indicators. All of these processes of search, selection and aggregation require decisions that are based on the knowledge, experience and values of those who make the search and selection. The best we can do is to accept the unavoidable subjectivity and to make these processes as systematic, scientific and encompassing as possible, i.e., comprehensive, complete and reproducible. This requires transparency and reproducibility of the process, a compact and systematic approach, and comparability of the results.

Science can help significantly in assuring that the processes of indicator search, selection and aggregation are as objective and circumspect as possible. Science provides extensive knowledge and complex models in most fields. Even if this information does not and never will represent ultimate truth, it can be used to inventory and structure available knowledge. In particular, it is important to avoid an *ad hoc* collection of indicators. The choice should be based on a consistent theoretical framework supported by sufficient empirical evidence. In this way, systematic methods for indicator search and selection can be developed that can assure reliable results if carefully applied.

### *Role of experts and the need for a participative process*

Letting a group of experts make a selection of indicators in an area as complex as sustainable development is, however, obviously the wrong method. *Because* they are experts, they are likely to focus on issues and items of their professional expertise while neglecting others that may have a significant effect in the real system. A search for indicators can only be as complete and comprehensive as the imagination, knowledge and experience of the investigators allow. But the best knowledge of systems and problems, including their long-term perspective, can usually be found with those who have to cope with them daily: citizens, unemployed persons, small business, managers and administrators, farmers, doctors, social workers, police and educators. Hence, this pool of intimate system and problem knowledge must be systematically included in the process of indicator search and selection. In addition to this effort to cover the full spectrum of *knowledge*, a similar attempt must be made to represent the full spectrum of *values*. While available *knowledge constrains* the search and selection of indicators, *values shape* it. It is, therefore, necessary to include all relevant world views and value perspectives of a community in a participatory search and selection process.

### *The Seattle process*

A participatory process for indicator selection is not a new idea. More and more communities[54] are using it. It is a necessity borne of the need to define an indicator set that can provide a full and complete picture of a problem situation or the viability of a given system. The search for a set of indicators of sustainable development can bring together citizens, administrators, business people and experts in a participatory process that strengthens sustainability-oriented planning and decision-making. In the following, a brief description of the Seattle Process is provided.[55]

***Step 1: Convene a working group representing a broad range of views and experience.*** The working group should consist of at least 10, but not more than about 25 people. They should represent the full spectrum of knowledge and values of the community for which the indicator set is sought. They should be selected for their ability to work together in a spirit of cooperation, despite their different views and backgrounds. They should be committed to meet regularly and to follow through with the process, even though it may take one or two years.

***Step 2: Define a statement of purpose.*** In the beginning of its work, the group must agree on and write down a statement of purpose. This statement should clearly delineate the objective in a way that can later serve to refocus the effort, should there be tendencies to shift the topic.

***Step 3: Develop the values and visions of the group.*** Unless the group is clear about the spectrum of values and visions within the group from the beginning, there will be endless ideological discussions about every individual indicator later. The group must try to identify and write down the common values and visions that are supported by all and which will be used later to select the indicator set. It must also record differences in values and visions between group members. They will later serve as critical test criteria for the comprehensiveness and completeness of the indicator set.

***Step 4: Review available data.*** Indicator sets should make as much use of available data as possible, but the available data should not determine the indicator selection! Survey data and regularly collected statistics can usually provide a large part of the data even for a complex set of indicators of sustainable development. Care must be taken, however, that indicators are not merely selected to fit available data. Often some indicators that are absolutely crucial for sustainable development have never been collected in conventional surveys. For this reason the drafting of an initial *tentative* indicator set, based on the method explained in this book, should precede the review of available data. This identifies an *ideal* set of indicators irrespective of their actual or potential availability. Every effort should be made to retain on this list indicators that are deemed important, even though data are currently not available for all of them.

***Step 5: Draft an initial indicator set.*** Based on the ideal set and information about available data, an indicator set is drafted by the group. The systematic viability assessment procedure explained in this book should be used at this stage to identify a compact and yet complete set of indicators. There are several important reasons for avoiding *ad hoc* selection: it is an extremely inefficient process; its results are unpredictable and shaped by spur-of-the-moment insights; the indicator lists produced in this way typically have large gaps in some important areas and are overly dense in others; the selection is shaped by a few vocal participants; and it is not reproducible. While limiting the number of indicators to a manageable set, the group must ensure that all important aspects are represented.

***Step 6: Involve community participation in critiquing and improving the indicator set.*** Once the group feels that it has developed a comprehensive set of indicators that fully represents its spectrum of knowledge and values, it must submit it to the wider community for critical review and improvement. This would involve publication in the local press, publication of brochures explaining the selection, public discussion, and public hearings. The feedback from this community participation serves to revise and improve the indicator set.

***Step 7: Involve experts in technical review of the indicator set.*** Even an extensive and participatory search and selection process is no guarantee for a good indicator set. Many of the indicators may involve technical issues that only experts in their respective fields can adequately address. A technical review of the indicator set by experts is essential. This is also true for the necessary check for completeness of the indicator set, based on the viability assessment procedure. However, the role of the experts should be very clear to all: they are called in to ensure precision, completeness and measurability of the set. They are not permitted to revise the indicator set according to their own limited view of the world.

***Step 8: Research for required indicator data.*** Indicator sets should make as much use of available data as possible. Survey data and regularly collected statistics can usually provide a large part of the data even for a complex set of indicators of sustainable development. However, it is highly unlikely that data for all indicators of the set will be readily available. Many will never have been collected. Often it will be possible to use combinations of existing statistical data to quantify a particular indicator. In this phase of the effort, the sources for the required indicator data have to be identified, and measurement programs for missing data have to be defined. Obviously, if it is impossible for organizational or financial reasons to obtain data for a particular indicator, a more accessible replacement will have to be found. But expediency should never be used as an excuse for not adopting and measuring an indicator for an aspect that is deemed essential.

***Step 9: Publish and promote the indicator set.*** Once the final indicator set is adopted, and means of quantifying all the indicators have been found, every effort must be made to ensure that it will be used by all sectors of society for the assessment of current conditions and the guidance of policy. The indicator set and the sources of information for it must be published and made widely available. It should be actively promoted to ensure that it will be used as a reference for public discussion of issues of sustainable development and related contexts. It is not necessary that the indicator set is formally adopted by political and administrative bodies. In fact, use of the set by non-governmental organizations as an instrument for checking and controlling government and administration may be much more effective.

***Step 10: Review and update the indicator set in a transparent, formal process.*** Sustainable development implies constant change, and the indicator set itself will have to be adapted to changing conditions. It is, therefore, necessary to provide for periodic review and update of the indicator set, its database and the values and visions underlying its conception. It seems advisable[56] to review and update the database every two years, to have a technical review every five years, to review every 10 years the values and visions, and to update the indicator set accordingly.

# 6. Defining and using indicator sets: examples

## 6.1. Sample applications: overview

As a practical guide for developing and using sets of indicators of sustainable development, several examples are presented in this chapter. They cover the range from a compact set of 21 indicators, to an extensive set of some 220 indicators, spanning applications from a city, state, nation and global region, to the world as a whole. These applications should be taken as examples and suggestions; they make no claim to being ideal.

The first application (Sec. 6.2) demonstrates the complete process of computer-assisted dynamic sustainability assessment for a compact set of 21 indicators for the state of the world. Indicator time series are selected from the Worldwatch Institute database. Formal assessment functions allow mapping indicator states on respective orientor satisfaction impacts. Results are presented in graphic form using orientor stars for the three component systems (social, support and natural system) and the total system.

The second set of applications (Sec. 6.3) shows how the recursive method of Table 4 is used to define indicator sets for a state, a nation and a global region (42 indicators each), also using three component systems. The method is also applied to the independently derived set of Seattle indicators, showing that the original results correspond to the results of the orientor-based derivation scheme.

The final application (Sec. 6.4) presents a comprehensive set of some 220 indicators for the sustainability assessment of a global region. Here, the total system is broken down into six component systems (individual development, social system, government and administration, infrastructure, economic system, resources and environment).

## 6.2. Assessment of global sustainability dynamics

### *Objectives*

The major objective of the present section is to demonstrate the method of orientor assessment using real data. To minimize the data collection effort and facilitate indicator selection, the up-to-date and widely available database of the Worldwatch Institute is used (Worldwatch Database Disk, January 1998). The selection of indicators from this database, the formulation of assessment functions, the formal assessment process, and assessment results for the state of the world from 1950 to 2000 are presented and discussed in some detail. The objective of this exercise is mainly pedagogic: to provide an example of how the method can be applied in practice and to demonstrate its possibilities and limitations. For this reason, a reduced set of 21 indicators (seven basic orientors with three component systems) is used. The results are a quick check. Nevertheless, they show some basic and interesting trends of global dynamics.

### *Method and database*

It is relatively easy to identify promising indicators using the orientor assessment questions of Table 4; it is much more difficult to find or collect corresponding time series data for the system for which the assessment is to be made.

The problem is avoided here by picking indicators from an available database. The Worldwatch Institute (1776 Massachusetts Ave., NW, Washington, DC 20036) publishes a semi-annual database disk containing time series of several hundred indicators from its regular publications (*State of the World, Vital Signs*, Worldwatch Papers). Most of these time series provide data at annual intervals, beginning in 1950. Since these indicators are collected to describe the state of the world, they cover a wide spectrum of concerns. As shown below, it is possible to identify from this database a set of indicators adequately covering the different facets of orientor satisfaction assessment.

While some regional and national indicators are found in the Worldwatch database, most indicators deal with global problems. The present assessment, therefore, also looks at the global system as a whole. As before, three major component systems are distinguished: the human system (social system, individual development and government), the support system (infrastructure and economy), and the natural system (environment and resources).

In the assessment scheme developed in this report (see Table 4), two separate assessments are required: one dealing with the viability of the component system itself, the other with its contribution to the viability of the total system. This requires a set of 42 indicators. In the present exercise, the two separate assessments are combined into one assessment, reducing the number of indicators to 21. Now, the relevant assessment question is: What is the state of satisfaction of orientor O of the total system with respect to (1) the human/social aspect, (2) the infrastructure/economy aspect, and (3) the environment/resources aspect of the total system?

The 21 indicators from the Worldwatch database were chosen for their ability to provide answers to the corresponding 21 questions. Since the database was collected for other purposes, it can hardly be expected that we would find indicators ideally matching those questions. For each of the indicators, the reasoning behind the choice is explained below.

### *Formalizing the sustainability assessment process*

Indicator selection is one unavoidable subjective component of the method; the other is the definition of the impact functions that map indicator states on orientor satisfactions. Except for simple cases, there is currently no method for objectively measuring indicator impact on orientor satisfaction. These impact functions have to be generated by subjective assessments. The reasoning behind the choice of each of the 21 impact functions is also explained below. Unfortunately, the Worldwatch database does not contain time series that could be used to define Biesiot-type indicators (see Sec. 4.3).

Despite the unavoidable subjectivity embodied in the method, it should not be dismissed as another subjective method. There is a decisive difference between the orientor assessment method and intuitive assessments: in our formalized method all steps and data and, in particular, the subjective components (choice of indicators and impact functions), are fully documented. They can be inspected, discussed, agreed to, rejected and changed. If a computer program is used—as in our case—it is a simple matter to change the subjective components and produce the corresponding assessment. There are no intuitive or hidden components, processes or factors that would influence the results. All conclusions can be reconstructed from the documented components of the formalized assessment process. All results are reproducible and cannot change with the mood of the investigator.

The complete assessment procedure, including graphic output, is programmed on an Excel worksheet. The program consists of the following sections for each of the three component systems and for the total system:

- Table of indicator time series (1950 to 2000) (one representative indicator for each basic orientor);
- Time graphs of indicators;
- Impact functions for each indicator;
- Orientor impact assessment tables for each indicator (time series 1950 to 2000);
- Time graphs of orientor impact for each indicator;
- Orientor star diagrams for 1950 to 2000 in 10-year intervals for each component system;

- Table of average orientor impact (from the three component systems) as measure of the orientor state of the total system; and
- Orientor star diagrams for 1950 to 2000 in 10-year intervals for the total system.

*Indicator selection and orientor satisfaction assessment*

The 21 indicators selected for this assessment are shown in Table 5. The file name and line number of the Worldwatch worksheet where the indicator is defined are also listed. The choice of each indicator, its time development, the choice of orientor impact function, and the assessment result for the time period from 1950 to 2000 are explained and presented in this section.

***Table 5. Indicator set using Worldwatch database (January 1998).***

| basic orientor | human system | support system | natural system |
|---|---|---|---|
| **existence** | Grain surplus factor GRNPROD.16/200 | Debt as share of GDP in developing countries DEBT.57 | World fish catch FISH.15 |
| **effectiveness** | Unemployment in European Union INCOME.83 | Gross world product per person GWP.11 | Grain yield efficiency GRNPROD.16/ FERTILIZ.14 |
| **freedom of action** | Share of population age 60 and over DEMOGRA.188 | Energy productivity in industrial nation PRDUCTVT.13 | Water use as share of total runoff WATERUSE.195 |
| **security** | Share of population in cities CITIES.14 | World grain carryover stock GRAIN:126 | Economic losses from weather disasters DISASTER.37 |
| **adaptability** | Persons per television set (1 TV per household) TVS.1 | Capital flow (public funds) to developing countries FINANCE.14 | Carbon emissions CARBON.20 |
| **coexistence** | Income share of richest 20% of population INCOME20 | Number of armed conflicts CONFLICTS.10 | Recycled content of US steel STEEL.71 |
| **psychological needs** | Refugees per 1,000 people REFUGEES.17 | Immunization of infants DISEASE.22 (DPT) | Chesapeake oyster catch RESOURCE.13 |

A few general comments about the choice of indicators and impact assessment functions are in order.

1. Each indicator is chosen to represent the particular aspect of orientor assessment for which it was selected, and only that aspect. It must be judged under that particular aspect only, not under others (for which it may also be relevant). An example: The number of hamburgers wolfed down by a customer can be taken as an indicator of his hunger, his gourmet taste, his wealth or his nutritional awareness. In an assessment, it must be clearly said how the indicator is interpreted. Care must be taken to avoid mixing up different concerns.

2. The restriction to one indicator for each orientor aspect and each component system is obviously a crude simplification. Each indicator must be understood as representing certain general trends; it should not merely be viewed within its own limited context.

3. Some indicators represent regional, not global developments. Their use is justified for the following reason: a chain is only as strong as its weakest link, and orientor theory requires that we choose indicators representing the *weakest* features of a system.

4. The impact assessment functions focus on one particular orientor aspect. This restriction must be strictly adhered to in making the assessment. An example: A certain amount of income inequality might be bad for COEXISTENCE, but good for EFFECTIVENESS. It is important to mentally separate these effects and to resist the temptation to generate a balanced assessment.

5. The impact assessment functions shown (in Figs. 10–12) are crude and angular; they could be drawn more smoothly. But these functions can only be defined by subjective assessments anyway, which must be open to discussion and alteration. In such discussions it is much easier to agree on the location of three or four breakpoints than on the exact shape of the curve.

6. A scale from 0 to 4 is used to grade orientor impact. The scale can be translated as follows: range 0 to 1 = red, completely unsatisfactory state; 1 to 2 = amber, danger; 2 to 3 = green, good condition; 3 to 4 = blue, excellent condition.

7. The last data points on most time series are for 1996 or 1997. The values shown for 2000 are extrapolated. For a few time series, data points for earlier years or intermediate years had to be found by estimates or interpolation. Fluctuations of two or three time series were smoothed by taking three- or five-year symmetric averages.

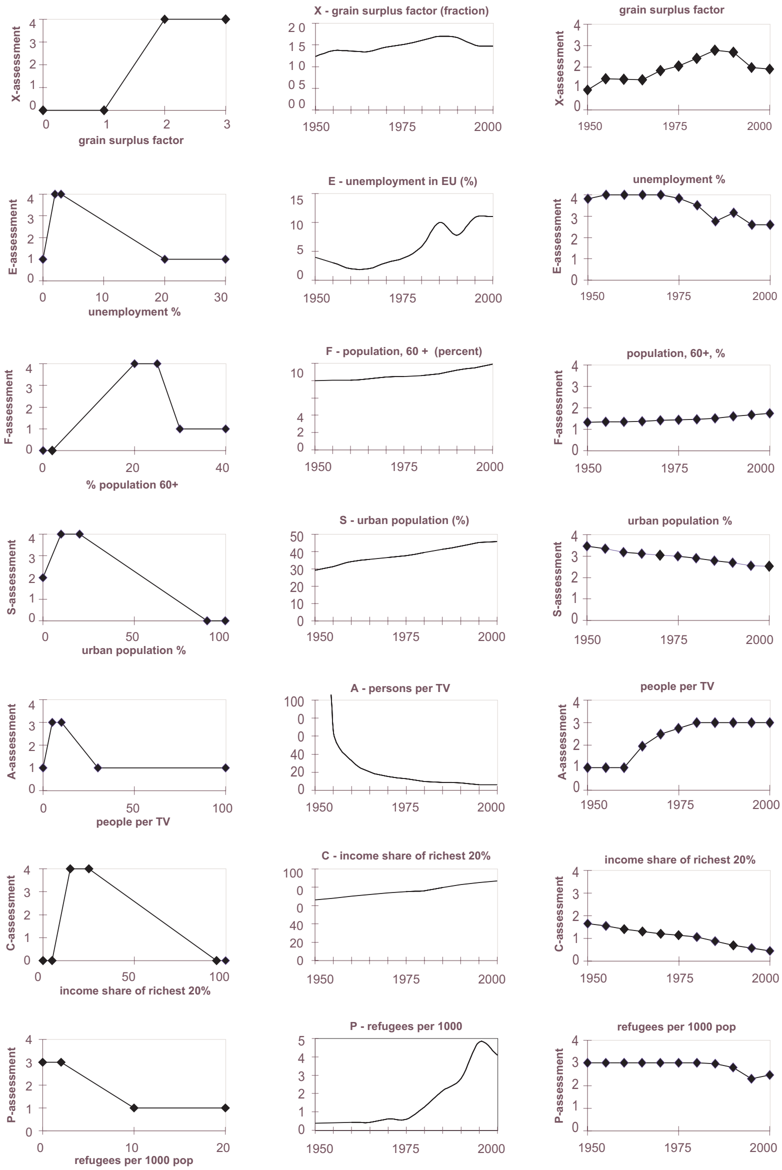


*Fig. 10. Basic orientor assessment for the human system (individual development, social system and government). Left column: assessment functions relating indicator state to orientor grade (0–1 = unacceptable, 1–2 = danger, 2–3 = good, 3–4 = excellent). Middle column: Worldwatch time series. Right column: orientor assessment of time series data for 1950–2000.*

## *Indicators and assessment functions for the human system*

For each of the seven basic orientors, the respective assessment function, the Worldwatch time series, and the result of the orientor assessment of that time series are plotted in Fig. 10 for the human system.

EXISTENCE: *Grain surplus factor*. This indicator is computed from Worldwatch data by dividing grain per person (kg) by minimum grain requirement for a pure grain diet (200 kg). The grain surplus factor indicates the amount of surplus grain that is now mostly fed to livestock; it is also an indication of the quality of the diet. This is reflected in the assessment function. Below a value of one, existence is not possible. Beyond a grain surplus factor of two, conditions are excellent with respect to EXISTENCE. The seemingly small variation of the time plot for the indicator translates into a much larger orientor impact variation.

EFFECTIVENESS: *Unemployment in the European Union*. The unemployment level of an industrialized region is used as an indicator of the global ability to generate and operate an effectively functioning human system. The assessment function reflects the fact that effectiveness is low for high unemployment as well as for vanishing unemployment. In the latter case effectiveness is low because it becomes difficult to find qualified labour to fill open positions.

FREEDOM OF ACTION: *Share of population age 60 and over.* A low share of older people in a population indicates low life expectancy and hence a significant loss of freedom of action for individuals. Assuming a rectangular steady-state age pyramid and a life expectancy of about 80 years, the share of the above-60 age group could not exceed a quarter of the population. If it is above this level, the FREEDOM OF ACTION of the human system is reduced as a result of the large share of the population that has to be supported in old age.

SECURITY: *Share of population in cities.* A large share of population in cities means a loss of self-support ability as well as mounting organizational and social problems. Disruptions of support functions will affect large parts of the population. Hence, SECURITY is reduced as the urban share increases. However, a vanishing urban share would indicate a deficit of central facilities and would also lead to security deficits. In the assessment function a security optimum is assumed for a low urban share of the population.

ADAPTABILITY: *Persons per television set.* Adaptability means that innovations and structural changes required by changing conditions are adopted in time to prevent deterioration of the system state. Television is an effective means of disseminating information, and is used here to indicate adaptability of the human system. The assessment function reflects the reasoning that television probably has its greatest effect on ADAPTABILITY if it is watched in small groups, stimulating discussion and social interaction. Television as an indicator represents developments in the entire information, communication and media technology and industry and their effects on adaptability.

COEXISTENCE: *Income share of richest 20% of population.* Large discrepancies in the distribution of income and wealth cause social stress and political unrest, increasing the risk of violent upheaval. Income inequality is used as an indicator of the satisfaction state of the COEXISTENCE orientor. Income equality (income share of the richest 20% = 20% of the total income) corresponds to optimum COEXISTENCE satisfaction.

PSYCHOLOGICAL NEEDS: *Refugees per 1,000 people.* Refugees are evidence of unacceptable conditions somewhere, of corresponding psychological stress of those affected, and related stress in social institutions.

### *Indicators and assessment functions for the support system*

For each of the seven basic orientors, the respective assessment function, the Worldwatch time series, and the result of the orientor assessment of that time series are plotted in Fig. 11 for the support system.

EXISTENCE: *Debt as share of GDP in developing countries.* Foreign debt indicates threats to existence of a country in two respects: (1) it is not self-supporting with respect to financing vital investments or operations—it could not exist for itself, and (2) moreover, a large part of any revenues are committed to unproductive servicing of debt, further deteriorating the EXISTENCE status. If foreign debt becomes substantial compared with the gross domestic product, EXISTENCE of the support system is in danger.

EFFECTIVENESS: *Gross world product per person.* The ability of the global economy to produce goods and services for a high material quality of life is a measure of its overall effectiveness. Beyond a certain level, however, more production will not correspond to further increases of effectiveness and may actually lead to its deterioration.

FREEDOM OF ACTION: *Energy productivity in industrial nations.* Increasing energy productivity means that more goods and services become available for the same amount of energy used. It can be expected that energy efficiency improvements are indicative of similar develop

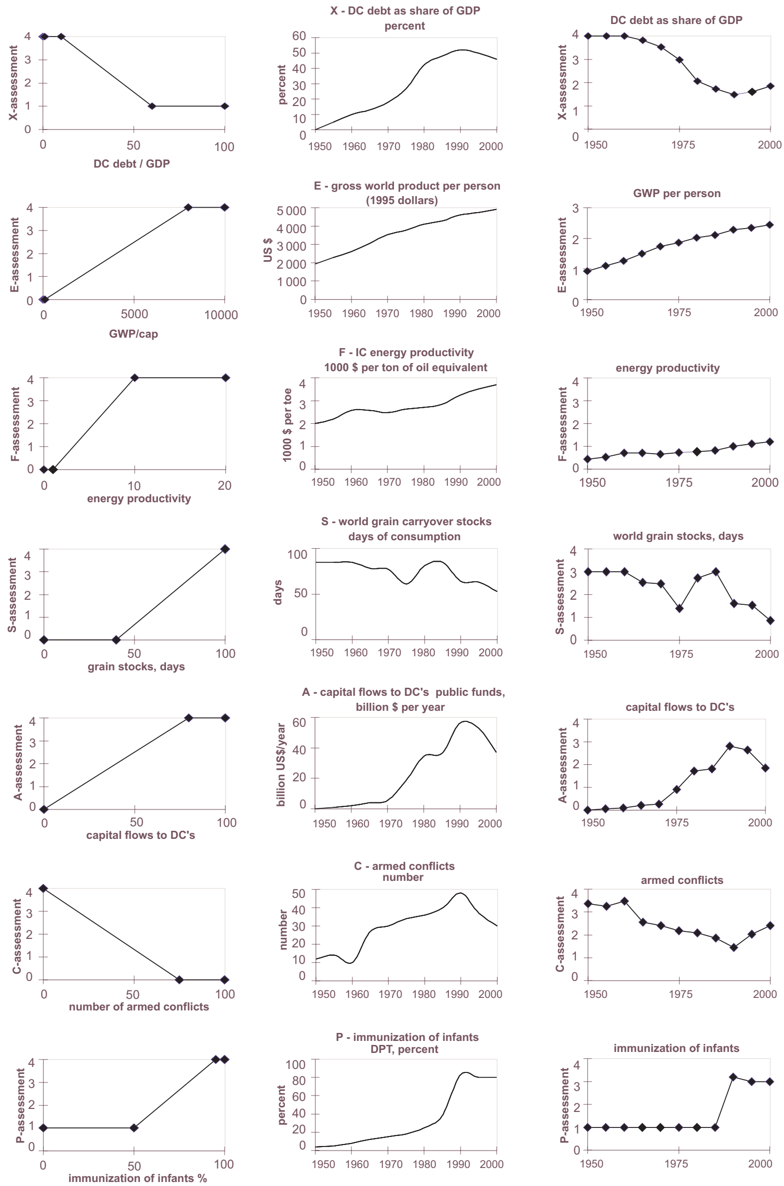


*Fig. 11. Basic orientor assessment for the support system (infrastructure and economy). Left column: assessment functions relating indicator state to orientor grade (0–1 = unacceptable, 1–2 = danger, 2–3 = good, 3–4 = excellent). Middle column: Worldwatch time series. Right column: orientor assessment of time series data for 1950–2000.*

ments in other parts of the support system. In this way, resources (energy, material and labour) are freed for other tasks: FREEDOM OF ACTION increases. The assessment function reflects the fact that energy productivity is currently far below its technological limit.

SECURITY: *World grain carryover stock.* A human population cannot survive without an adequate supply of grain. As harvests are seasonal, grain stocks must allow adequate nutrition for all until the next harvest. To guard against the risk of harvest failures, grain stocks must actually be larger than this minimum. The world grain carryover stock is used as an indicator for the SECURITY of the support system.

ADAPTABILITY: *Capital flow from public funds to developing countries.* This capital flow is an indicator not only of surplus produced in an economy, but also of willingness to spend it elsewhere to change existing conditions. It is indicative of the potential for adaptive change, i.e., adaptability.

COEXISTENCE: *Number of armed conflicts.* Armed conflict indicates a breakdown of peaceful coexistence between different populations. The number of armed conflicts at a given time is an indicator of the satisfaction status of the COEXISTENCE orientor.

PSYCHOLOGICAL NEEDS: *Immunization of infants.* The availability of adequate health care reduces suffering and stress significantly. The share of children who are immunized against common communicable diseases is a measure of the availability of health care and similar services. It is used to assess the satisfaction of the PSYCHOLOGICAL NEEDS orientor.

### *Indicators and assessment functions for the natural system*

For each of the seven basic orientors, the respective assessment function, the Worldwatch time series, and the result of the orientor assessment of that time series are plotted in Fig. 12 for the natural system.

EXISTENCE: *World fish catch.* Despite or because of an enormous expansion and modernization of the world's fishing fleet the world fish catch has been stagnating for almost a decade. In some areas, fish populations have collapsed. The stagnating fish catch is an indication that the marine ecosystem is being harvested at or beyond its sustainable limit. The world fish catch is taken as an indicator for the EXISTENCE status of the natural system. *Note:* The assessment function used here refers to sustained catch and assumes that fish populations will recover if annual catch is reduced.

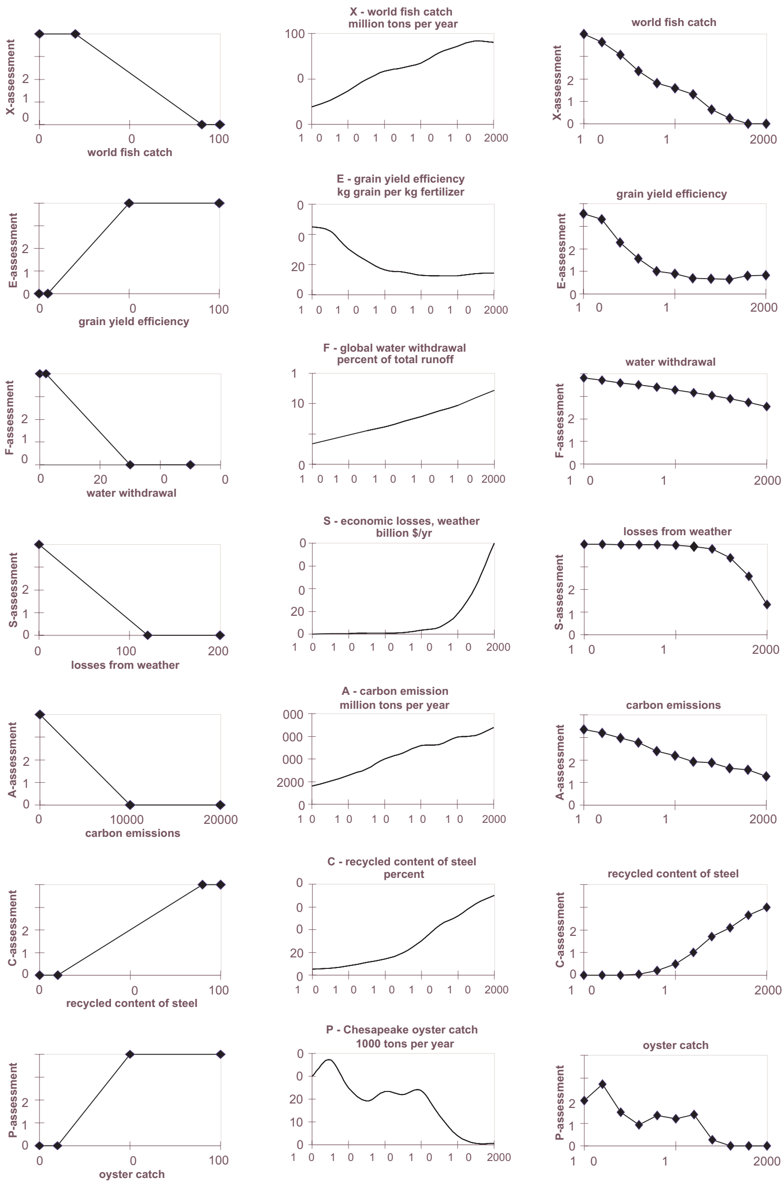


*Fig. 12. Basic orientor assessment for the natural system (environment and resources). Left column: assessment functions relating indicator state to orientor grade (0–1 = unacceptable, 1–2 = danger, 2–3 = good, 3–4 = excellent). Middle column: Worldwatch time series. Right column: orientor assessment of time series data for 1950–2000.*

EFFECTIVENESS: *Grain yield efficiency.* As populations increase and economies grow, more people become richer and can afford more meat in their diets. Agricultural production is challenged by the task of producing more food and feed grain on a shrinking grain land area in increasingly polluted and eroded soils. The loss in productive efficiency of the land is reflected in the decreasing ratio of grain produced to fertilizer applied. This change in grain yield efficiency is assumed to be indicative also of developments in the natural system at large. Grain yield efficiency is used as an indicator for EFFECTIVENESS of the natural system.

FREEDOM OF ACTION: *Water withdrawal as share of total runoff.* If a greater share of the total water runoff is withdrawn for use by the human system, less remains for the natural system, ecosystems and their organisms. Water withdrawal is an indicator for the remaining FREEDOM OF ACTION of the natural system.

SECURITY: *Economic losses from weather disasters.* The dramatic increase of economic losses from weather disasters is already being used as an indicator of human interference with natural processes. It is used here to assess the SECURITY of the natural system, i.e., its ability to hold risks at levels that pose no permanent threats to the viability of the system.

ADAPTABILITY: *Carbon emissions.* Only a small part of carbon emissions from the human support system can be absorbed by the natural carbon cycle. Most of the emissions lead to a rising level of carbon dioxide in the atmosphere, and corresponding temperature increase and climate change. As the excess of human over natural carbon emissions increases, ecosystems and organisms are less and less able to adapt to the consequences. The ratio of human carbon-emissions to natural carbon-emissions in the carbon cycle (assumed at 100 billion tonnes of carbon a year) is used to assess the effect on the ADAPTABILITY state of the natural system.

COEXISTENCE: *Recycled content of steel.* The sustainable systems of nature have recycled all matter for several billion years. Human use of natural resources without recycling implies continuing and accelerating depletion of these resources. The share of recycled material in products is an indication of how close a system is to sustainability. The recycled content of steel is used as an indicator for the COEXISTENCE state of the natural system as it is affected by the support system. It is assumed that this indicator also represents similar efforts with respect to other key materials.

PSYCHOLOGICAL NEEDS: *Chesapeake oyster catch.* The concern of people about the state of the environment, and their psychological stress about the loss of species, ecosystems, beauty and evolutionary potential is often connected to specific environmental tragedies. Although a regional development, the Chesapeake oyster catch is used as a representative indicator to assess the state of the PSYCHOLOGICAL NEEDS orientor.

### *Dynamics of orientor satisfaction 1950 to 2000*

It is difficult to discern a coherent picture of the state of the world and its dynamic development from 1950 to 2000 from the 21 tables or time graphs of either the indicators or their orientor impact assessments in Figs. 10–12. Developments become much more obvious in the orientor star diagrams for each of the component systems and the total system. These are presented separately for the years from 1950 to 2000 in 10-year intervals.

***Human system.*** The 50-year dynamics of the global human and social system are shown in Fig. 13 (left). The system progresses from a rather unbalanced satisfaction of orientors in the earlier decades to a more balanced but still deficient satisfaction in later decades, with the obvious exception of the coexistence orientor. Its inadequate state is caused by the rising income gap between the rich and the poor.

***Support system.*** Orientor satisfaction dynamics for the support system are shown in Fig. 13 (right). Initially extremely unbalanced, the orientor satisfactions relative to the support system (infrastructure and economic system) become more balanced in later decades, although at unsatisfactorily low levels.

***Natural system.*** The dynamics of orientor satisfaction of the natural system in Fig. 14 (left) reflect very clearly the continuing degradation of this system. At the beginning of the period the system appears in good shape with one exception: the coexistence orientor is already in an unacceptable state. This is because of wasteful use of resources (without any recycling attempt) threatening the sustainability of the system.

***Total system.*** The average satisfaction ratings of the three component systems combined are shown in the orientor stars of Fig. 14 (right). They show a much more balanced state of orientor satisfaction, although at a low and steadily decreasing level. These graphs conceal the rather more dramatic developments evident from the orientors stars of the three component systems. Referring back to the orientor stars for the three component systems, it becomes evident that any improvements appearing in the diagrams for the human and the support system are clearly coupled to corresponding viability losses in the natural system.

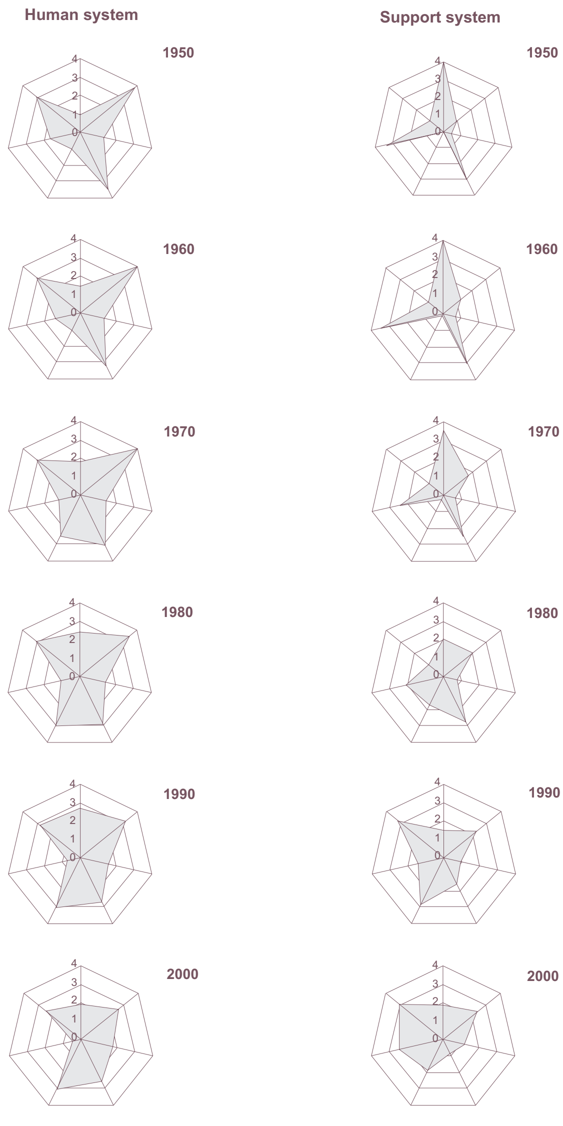


*Fig. 13. Orientor stars for the human system and the support system for 1950–2000.*

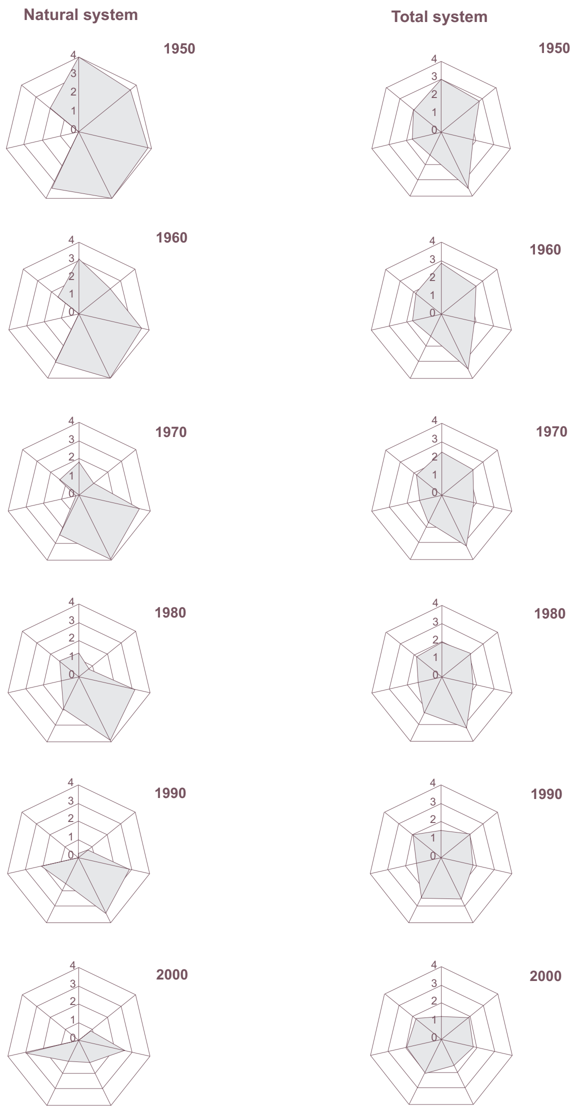


*Fig. 14. Orientor stars for the natural system and the total system for 1950–2000.*

### *Discussion and conclusions*

Experience with this state of the world assessment leads to some observations and conclusions:

1. Assessment of satisfaction of a particular orientor now hinges on the state of a single indicator. This is acceptable if the indicator is either fully representative of dynamic trends with respect to that orientor and that particular component system, or if it represents the weakest link, without which the system could not function properly. If neither of these cases applies, then a proper aggregate index made of several informative indicators should be found and used (see Sec. 5.3).
2. Some of the indicators used in the state of the world assessment had to be used for lack of something better in the Worldwatch database. Proposals for more adequate indicators are made in the set of 42 indicators presented in Table 9 (below), and the set of some 220 indicators shown in Tables 10–15 (below).
3. As mentioned in the beginning, both the indicator selection and the definition of the assessment functions are highly subjective processes. If different choices are made, different results can be expected. An important advantage of the method is that these selections have to be explicitly documented, and that they can be easily changed to experiment with different choices within legitimate factual limits.
4. The time sequence of orientor stars clearly brings out the dynamics of stresses and threats to a system and allows tracing their origins.

## 6.3. Compact indicator sets

The method of finding indicators of sustainability by considering measures of basic orientor satisfaction (Table 4) is completely general. It can be applied to a family, a firm, or a country, as well as to an individual. This section presents some examples for a city, a state, a country, and a global region. In all of these cases, the total system is visualized as being composed of three major subsystems (human system, support system and natural system), as explained in Sec. 2.3. In each case, only one representative indicator is adopted for each system and orientor category, hence each indicator set contains 42 indicators. From these examples, it will be clear that we cannot hope to capture essential aspects relevant to sustainable development in one simple indicator or index such as GDP, nor even a handful of indicators. Rather, a set of the order of some 40 or more indicators appears to be necessary.

## *Indicator set for a city: Seattle*

In the transition process to sustainable development, the community may be the most crucial component. (The term community as used here refers to a political entity at the level of village, town or city). The community is the smallest cell of human interaction that contains all the vital subsystems that we find in the larger units (cities, states and nations) of human society:

***Individual development:*** Schools and other educational institutions, sports and recreation facilities, libraries, places of worship.

***Social system:*** Population size and growth, social structure, ethnic composition, cultural diversity, income distribution, employment, clubs, social problems, welfare and social security, crime.

***Government system:*** Community administration, citizen participation, non-governmental organizations.

***Infrastructure system:*** Roads, buildings, hospitals, water supply, sewer lines and sewage plant, electric power supply, telephone system.

***Economic system:*** Shops, markets, businesses of all kinds, banks.

***Resources and environment:*** Waste generation and disposal, recycling, energy efficiency of public and private buildings, material balances of plants, ecological footprint of community, parks and wilderness area.

For practical reasons, it is advisable to aggregate the six sector subsystems into three subsystems as suggested earlier: human system (individual development, social system and government), support system (infrastructure and economic system), and natural system (resources and environment).

For any community, a set of indicators can always be found by going through the basic orientor assessment questions of Table 4 for each of the subsystems, and finding indicators that can answer those questions for the particular circumstances of the community.[57] This work will already produce a much better understanding of the community as a living system integrated in the global system, of its needs and functions, and of its potential to contribute to sustainable development of the global system.

There is such a diverse spectrum of communities in the world that it is impossible to find a set of indicators that would apply to all of them. For some, the run of wild salmon in the local river[58] might be an important indicator of environmental quality, for others, it might be the air pollution by a local steel mill. Some communities, trying to provide essential services, might have to count the number of outdoor latrines per 1,000 people, while others may include the efficient use of methane from their sewage plant for electric power generation in their indicator list.

***Table 6. Indicators of sustainable development for the city of Seattle (original set).***

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| **existence** | human | Children living in poverty | Low birthweight infants |
| | support | – | – |
| | natural | – | – |
| **effectiveness** | human | Health care expenditures | Distribution of personal income |
| | support | Residential water consumption | Work required for basic needs |
| | natural | Impervious surfaces | Solid waste generated and recycled |
| **freedom of action** | human | High school graduation | Housing affordability ratio |
| | support | Real unemployment | Voter participation |
| | natural | Renewable and nonrenewable energy use | Farm acreage |
| **security** | human | Employment concentration | Juvenile crime |
| | support | Community capital | Emergency room use for non-ER purposes |
| | natural | Soil erosion | Pollution prevention and renewable resource use |
| **adaptability** | human | Adult literacy | Youth involvement in community service |
| | support | Library and community centre usage | Vehicle miles travelled and fuel consumption |
| | natural | Biodiversity | Wetlands |
| **coexistence** | human | Volunteer involvement in schools | Ethnic diversity of teachers |
| | support | Air quality | Asthma hospitalization rate for children |
| | natural | Wild salmon | Population |
| **psychological needs** | human | Equity in justice | Neighbourliness |
| | support | Pedestrian friendly streets | Perceived quality of life |
| | natural | Gardening activity | Open space in urban villages |

*Only two original Seattle indicators were not used in this scheme: public participation in the arts and arts instruction.*

Comprehensive indicator systems have been derived by citizen groups in many cities.[59] A famous and often copied example is the set of indicators of sustainable development for the city of Seattle, Washington. This set is the result of a long process of discussion and development, involving intensive citizen participation, as explained in Sec. 5.5. Table 6 shows this set of indicators in an orientation-theoretic scheme corresponding to Table 4. Remarkably, there is an almost perfect correspondence between the original set and the orientor-based scheme (with the exception of two indicators pertaining to the arts). This seems to indicate that the Seattle indicators are indeed comprehensive, covering all important aspects of basic orientor fulfillment for viability and sustainability.

As a general rule, indicators will be region-specific, especially here with its 'wild salmon runs.' Obviously, the indicator sets for a village in Lapland and a village of similar size in West Africa would be quite different, although overall conclusions concerning the sustainability of each system could again be comparable.

*Indicator set for a state: Upper Austria*

Indicator sets for sustainable development of small geographic regions will have to reflect specific regional concerns. Using the basic orientor framework, a tentative set of 42 indicators for sustainable development has been developed for the federal state of Upper Austria.[60]

Table 7 presents the provisional indicator set for this state. The set was developed by a working group of about a dozen scientists, planners and government officials from that state in response to an explicit mandate from the state legislature to develop a set of indicators for monitoring progress in the official sustainable development program of the state. The orientor-based approach (Table 4) was used to obtain this set.

The indicator set was developed by the group in a three-day workshop at a remote conference site. The participants had familiarized themselves with the orientor-based approach by reading some introductory materials, roughly equivalent to the present book. However, the systems approach and the basic orientor concepts were new to them, and the first day was spent on identifying the relevant systems, their boundaries, and mutual relationships, i.e., the human system, support system, natural system and the total system, and on discussing the meaning of the orientor questions (of Table 4) with respect to these systems.

On the second day, the group split into three working groups, each working on indicators for one of the three subsystems. For each of the seven basic orientors, potential indicators were identified for subsystem performance, and its contribution to the total system. The corresponding 7x2 matrix was eventually filled by some three to 10 proposed indicators for each slot. Some care was taken at this point to make sure that the proposed indicators could be procured, at least in principle.

The full list of indicators developed by the three working groups was discussed and modified in plenary on the third day. For each of the 42 slots in the scheme, one preferred indicator was identified. Other indicators identified as useful were kept as supplemental indicators. Within a few weeks after the workshop, the list was modified by the workshop organizers, based on additional comments and suggestions submitted by the workshop participants.

Participants connected to the state government's statistical office then tried to match the indicators as far as possible with existing time series. Obtaining time series data for this indicator set turned out to be more difficult than expected, as most of the information is collected at the national level only. Unfortunately, due to a change in government, the project lost the necessary financial and humanpower support. At the time of this writing, the work has not been completed and the indicator set has not been officially adopted.

***Table 7. Compact set of indicators of sustainable development for the state of Upper Austria.***

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| **existence** | human | Number of full-time employed people as fraction of population | Rate of change of life expectancy |
| | support | Ratio of investment rate for renewal to depreciation rate | Rate of change of number of farms |
| | natural | Rate of change of species diversity | Fraction of essential life support systems originating in the region |
| **effectiveness** | human | Number of state employees as fraction of population | Fraction of population below poverty level |
| | support | Average residence time of consumer goods (value of stock/purchases/year) | Ratio of average income to poverty level |
| | natural | Fraction of total area with polluted groundwater supply | Fraction of renewable energy in total energy consumption |
| **freedom of action** | human | Fraction of state revenue that is required to meet existing commitments | Average education level (school years) |

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| | support | Fraction of industrial capital controlled by foreign interests | Weekly work hours required to secure basic needs at actual minimum wage |
| | natural | Fraction of total area covered by natural forest | Fraction of occupations depending on regional resources (>1% of employed) |
| **security** | human | Rate of change of state debt (percent per year or $ per capita per year) | Crime rate |
| | support | Bankruptcies per year as fraction of total enterprises | Emission rate of persistent wastes and pollutants (chlororganic, radioactive) |
| | natural | Fraction of agricultural and forest area threatened by soil erosion | Depletion rate of non-renewable resources |
| **adaptability** | human | Average number of months before unemployed person finds new work | Ratio of newly evolving professions and training programs to existing ones |
| | support | Diversity of industrial and commercial activity | Qualifications demanded in the labour market (diversity, level) |
| | natural | Land use: rate of increase of sealed surfaces per year | Degree of utilization of total primary production |
| **coexistence** | human | Fraction of women in upper management (private and public) | Value of voluntary services as fraction of total services |
| | support | Consumption of nonrenewable resources per capita per year | Fraction of enterprises using environmental accounting (eco-audit) |
| | natural | Income fraction from agriculture, forestry and tourism | Fraction of protected natural areas of transregional importance |
| **psychological needs** | human | Fraction of adult population with alcohol and drug addiction | Suicide rate |
| | support | Fraction of population within walking distance of essential services | Fraction of population leaving because of infrastructural deficits (percent/yr) |
| | natural | Fraction of population living near (< 2 km) large forest or park areas | Number of overnight stays by tourists per capita of population |

***Table 8. Compact set of indicators of sustainable development for New Zealand.***

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| **existence** | human | Children in poverty | Violent crime rate |
| | support | Ratio of investment and maintenance to depreciation rate (built capital) | Percent of people with inadequate access to general services |
| | natural | Depletable resources lifetime | Percent of carrying capacity used at current lifestyle |
| **effectiveness** | human | Voluntary social services involvement | Households living below poverty level |
| | support | Percent of GDP going to education (incl. ACE) | Housing affordability |
| | natural | Greenhouse gases (e.g. tonnes $CO_2$/$GDP) | Renewable fraction of total materials and energy resources used |
| **freedom of action** | human | Income security and employment security | Average education level—adult literacy, tertiary qualifications level |
| | support | Fraction of infrastructure capital controlled by overseas interests | Hours of paid work required to meet basic needs at actual minimum wage |
| | natural | (Renewable resource use)/ regeneration | Supply redundancy—energy, water, food |
| **security** | human | Ratio of dependents/ producers | Government financial and political security |
| | support | Bankruptcies, fraction per year | Percent of population with basic needs satisfied |
| | natural | (Ecological footprint)/ (sustainable footprint) | Percent dependence of vital supplies on sources not under regional control |
| **adaptability** | human | Subsidiarity extent | Public participation in voluntary activities in community |
| | support | Diversity of industrial and commercial activity | Percent of workforce in small business |
| | natural | Rate of development of renewable resources/ depletion of nonrenewables | Ability of essential infrastructure to shift to alternative resource base |
| **coexistence** | human | Extent of community commitment to sustainability | Ratio of top to bottom incomes |

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| | support | Nonrenewables consumption per capita | Use of environmental accounting by firms |
| | natural | National income fraction from sustainable agriculture, forestry and tourism | Fraction of resource use dependent on international commons (atmosphere, oceans, and so on) |
| **psychological needs** | human | Alcohol, tobacco and drug consumption | Youth suicide rate |
| | support | Dominance of commercial demands (e.g. privatization of essential services) | Anxiety/concern/unhappiness over infrastructural and economic problems |
| | natural | Accessibility of outdoors to city dwellers | Level of anxiety/concern about resources, environment and the future |

*Table 9. Compact set of indicators of sustainable development for global regions.*

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| **existence** | human | Accumulated public debt per capita as fraction of mean annual income | Share of population living in urban areas (no subsistence self-sufficiency) |
| | support | Net growth of built capital (infrastructure and economic system) | Infant mortality |
| | natural | Rate of degradation and loss of agricultural land and forests | Grain production per person per year |
| **effectiveness** | human | Share of population affected by unsolved social problems | Share of population below poverty level |
| | support | Amount of grain that can be bought for one hour minimum wage | Average personal income vs. subsistence level income |
| | natural | Land area fraction with polluted groundwater | Renewable fraction of energy and material resources |
| **freedom of action** | human | Unemployment rate: percent of working age adults who cannot find paid work | Annual growth rate of population |
| | support | Energy productivity (kWh/$GDP) | Life expectancy at birth |

| orientor | subsystem | subsystem performance | contribution to total system |
|---|---|---|---|
| | natural | Average atmospheric acid deposition (kMol $H^+$ per ha) | Share of land in natural state or under sustainable management |
| **security** | human | Burden of diseases and injuries (disability adjusted life years) | Net rate of refugee generation or absorption, percent of resident population |
| | support | Foreign trade as share of total domestic trade volume (dependence) | Rate of change of ecological footprint |
| | natural | Biocide resistant strains as fraction of total harmful strains and species | Share of vital dependence on water supply not under regional control |
| **adaptability** | human | Average length of formal education of females | Average per capita membership in non-governmental organizations (public interest) |
| | support | Ratio of entrepreneurs to government employees (college graduates) | Ratio of tax revenue to long-term committed state expenditures |
| | natural | Ecological diversity index | Rate of development of renewables vs. rate of depletion of nonrenewable resources |
| **coexistence** | human | Prison population as share of total population | Percent of population able to converse in more than one language |
| | support | Ecological footprint vs. permissible sustainable footprint | Vertebrate species extinct and at risk as fraction of total in 1900 |
| | natural | Rate of change of ecological diversity index | Cumulative use of chlorinated hydrocarbons (g/ha) |
| **psychological needs** | human | Income ratio of richest 20 percent of population to poorest 20 percent | Percent moving because of social and political problems |
| | support | Percent of population within one hour of all essential services | Percent moving because of inadequate support structure |
| | natural | Wilderness area as share of total land area | Percent moving for the sake of their children's health |

### *Indicator set of a country: New Zealand*

Sustainability can only be discussed in relation to a well-defined region, since it is directly related to its carrying capacity. This may require including indicators in one region that would not be appropriate in another.

By way of illustration, Table 8 shows a draft list of indicators for New Zealand /Aotearoa, derived in this manner by John Peet by reference to the specific social, economic, political, environmental and resource conditions of that country.[61] Note that the list reflects the more-or-less subjective opinions of only one person. In practice, it should be the outcome of a much more representative process and be subject to peer and community review.

### *Indicator set for a global region*

In Table 9 a compact set of sustainability indicators for an unspecified, general global region is shown. In choosing these indicators, particular attention was paid to two aspects: potential availability of data and comparability of results. The indicators were selected to correspond as much as possible to time series data available for most countries; for example, in publications of the United Nations and the annual publications of the Worldwatch Institute and the World Resources Institute.[62] In addition, indicators were selected that carry the same significance and meaning in countries at very different stages of industrial development. The set is more general than that used for the assessment of sustainability dynamics in Sec. 6.2, which had to be restricted to available Worldwatch data series.

The indicator set was generated by one person (HB) and should be subjected to critical review and revision before adoption. The indicators chosen should be understood as suggestions. There may be other indicators that are easier to obtain or that answer the relevant orientor question just as well or better. The important point is that the chosen indicator or indicators must provide a reliable answer to a particular orientor question.

## 6.4. Extensive indicator set for a global region

It was mentioned earlier (Sec. 5.5) that, ideally, indicator sets should initially be developed without reference to available data sets. Since existing statistical observations have rarely been collected with a view toward problems of sustainable development, it is all too likely that such data sets already reflect a rather narrow view, often restricted to economic concerns.

Also, it was pointed out in Sec. 4.3 that the most useful indicators for sustainability assessments are provided by Biesiot ratios, i.e., ratios of the rate of system response to the rate of system threat with respect to a particular basic orientor satisfaction. Data for such indicators are rarely collected now, but their eventual collection should be an urgent priority.

In more comprehensive sustainability assessments, it is necessary to consider a more detailed picture of the total system, i.e., to disaggregate beyond the three subsystems used in all of the previous assessments. Also, the choice of just one representative indicator for each orientor concern and each subsystem will often only be an inadequate caricature of the real situation.

In Tables 10–15, a much more complete set of indicators is shown for the six subsystems: individual development, social system, government and administration, infrastructure, economic system, resources and environment. For each category of concern, multiple indicators covering different aspects are presented. (The letters and numbers following these indicators indicate more conventional categories: N – normative and ethics, P – psychological, Q – qualification, O – organizational, L – living condition, W – welfare and social condition, M – material resource, F – financial and economic, D – dependence, B – environmental burden indicators.[63] Note that some indicators are used in several orientor satisfaction categories.).

These multiple indicators can be used as indicated in Sec. 5.3, either concentrating on those in the worst condition as the weakest links of a particular orientor satisfaction category, or using them to provide an aggregate assessment for that category.

***Table 10. Indicators of sustainable development for individual development in a global region.***

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **existence** | Individual lifetime fraction required for sufficient life support #L24<br>Avoidable mortality and disability as fraction of total mortality and disability #L30<br>Infant mortality rate #L05 | Fraction of population that could supply and support itself in case of emergency #W10<br>Rate of change of income inequity #W04 |
| **effectiveness** | Lifetime fraction in meaningful, fulfilling activities #L27<br>Effectiveness of political and social participation #O23<br>Lifetime fraction lost in illness and disability #L28 | Percent adult population with organizational and management skills (paid or unpaid) #Q11<br>Sustainability index of region #B27<br>Rate of change of regional carrying capacity #B26 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **freedom of action** | Life expectancy at birth #L06<br>Frequency of violations of basic human rights #N02 | Spectrum of qualifications, personal skills, experience #Q08<br>Percent of employees with narrow specializations only #Q09 |
| | Percent of individual life determined by external forces (bureaucracy, customs, caste, social norms) #P08<br>Percent of population politically active at all levels of self-government and NGOs #O24<br>Creative potential (artists, writers, scientists per 1,000 people) #Q18<br>Political alienation (percent of population identifying with forces in power) #P13<br>Adult literacy rate #L19 | Percent of essential production generated within region #D02<br>Rate of material or financial surplus generation as fraction of total investment #F14 |
| **security** | (Average savings or debt)/ (annual income) #W09<br>Avoidable mortality and disability as fraction of total mortality and disability #L30<br>Probability of being able to adhere to life-plan #Q15<br>Percent of major personal risks covered by insurance or social safety net #W12 | Average value of property access (private or communal) in terms of average annual income #W11<br>Average ratio of job competence vs. job competence requirements (business and industry, administration, politics, science, education) #Q10 |
| **adaptability** | Spectrum of personal skills, qualifications, experience #Q08<br>Lifetime fraction in education and training #Q04<br>Personal freedom to pursue new paths #Q16<br>Percent of adult population continuing education after formal education ends #Q19 | Spectrum of qualifications, personal skills, experience #Q08<br>Ability to change behavioural norms pragmatically by reference to needs and firm ethical background #N10<br>Average years in one job or position #Q14 |
| **coexistence** | Lifetime fraction of societal contribution of individual vs. personal gain #W25<br>External burden on environment because of personal demands #B03<br>Burden on future generations due to excessive demands #W01 | Average intensive international contacts per capita and year #D12<br>Environmental footprint vs. sustainable footprint #B01<br>Rate of change of environmental footprint #B02 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| | | Future debt footprint (debt payback time) #F10<br>Rate of change of future debt footprint #F11 |
| **psychological needs** | Index of personal happiness (well-being) #P07<br>Degree of social inequity (percent of population under discriminatory conditions) #W01<br>Education equity index (years of education of best vs. least educated 10 percent) #Q05<br>Lifetime fraction available for leisure #L26<br>Lifetime fraction in meaningful, fulfilling activities #L27 | Anxiety related to individual development and self-determination (percentage of respondents seeing serious problem) #P04<br>Percent of population who would rather live elsewhere for reasons of individual development #P10 |

***Table 11. Indicators of sustainable development for the social system of a global region.***

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **existence** | Net population growth rate #L02<br>Rate of change of social service capacity #W14<br>Security of funding or secure social processes for next five years #W15 | Rate of change of social problems (situation of poor) #W07<br>Rate of change of birth rate #L04<br>Rate of change of life expectancy at birth #L07<br>Rate of change of income inequity index #W04<br>Percent of population dependent on public welfare system #W08 |
| **effectiveness** | Fraction of working age population employed (paid or unpaid) in social service work #W23<br>Social service unit cost #W22<br>Ratio of volunteer services hours to paid services hours #W24<br>Health cost of environmental pollution #B31 | Percent of social needs effectively dealt with by system #W13<br>Percent of population in hospitals, jails, mental institutions #L23<br>Percent of population with income below sufficiency level #W06 |

| orientor | subsystem performance | contribution to total system |
| --- | --- | --- |
| | Percent of GDP going to graft, corruption, politically motivated subsidies, and so on #O12 | |
| **freedom of action** | Unemployment rate: percent of working age adults who want to but cannot find work #W17<br>Social service unit cost per serviced person vs. average annual income #W22<br>Percent of social needs effectively dealt with by system #W13<br>Rate of change of unemployment rate #W18 | Potentially available uncommitted funds as fraction of total budget #O04<br>Fraction of population employed (paid or unpaid) in social service work #W23<br>Social problems as percent of active political issues #W05 |
| **security** | Social support ratio: (children + old people + sick + unemployed)/(working population) #W20<br>Rate of change of social support ratio #W21<br>Probability of adequate financing or social support processes in 20 years #W16 | Social problems as percent of active political issues #W05<br>Percent share of environmental degradation due to poverty #B33<br>Rate of change of social problems #W07 |
| **adaptability** | Fraction of self-organizing (NGO) vs. total social activity #O28<br>Level of institutional bureaucracy: bureaucrats per working adult #O15<br>Average quality and level of education and skills #Q07<br>Percent of population reached by quality media information #Q17 | Average active individual membership in social groups, clubs, NGOs per capita #O25<br>Inertia of social norms: rate of change of social norms and behaviour #N11<br>Educational level of least educated 20 percent of population #Q06 |
| **coexistence** | Degree of social equity (e.g. percent of population under discriminatory conditions) #W01<br>Burden on future generations because of excessive demands #W02 | Percent of population born elsewhere (language compatibility, diversity) #D11<br>Import or export of social problems (migration, foreign assistance) #D10<br>Burden on future generations because of excessive demands #W02<br>Work distribution index #W19<br>Proportion of undernourished children #L09 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| | | Income distribution (richest vs. poorest) #W03<br>Social problems as percent of active political issues #W05<br>Degree of social inequity #W01 |
| **psychological needs** | Average size of cohabiting family unit #W26<br>Average rate of intense family-type social contacts per day #W27<br>Average distance between living places of members of extended family #W28<br>Average proximity of places of rest, beauty, spirituality, culture #P15 | Anxiety related to social problems (percent of population seeing serious problem) #P03<br>Fairness level (percent of population seeing system as extremely unfair) #N06 |

***Table 12. Indicators of sustainable development for government and administration of a global region.***

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **existence** | Budget balance (± percent of total expenditures vs. total government revenues) #O03<br>Annual debt service cost vs. revenues #F08<br>Average debt per capita vs. cost of living #F09 | Problem solving time (problem stock vs. rate of problem solving) #O8<br>Percent of problems solved by government and administration (compared with those solved by neglect, business and industry, NGOs, or international agents #O9 |
| **effectiveness** | Level of institutional bureaucracy: bureaucrats per working adult #O15<br>Problem solving time (problem stock vs. rate of problem solving) #O08 | Problem solving time (problem stock vs. rate of problem solving) #O8<br>Relative cost of government per capita vs. cost of living #O05<br>Percent of crimes leading to solution and conviction #O11 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **freedom of action** | (Annual debt service cost)/ (total revenues) #F08<br><br>Free administrative capacities and funds (percent of total) #O13 | Frequency of democratic elections and referendums #O26<br><br>Spectrum of political opinion (media) #O19<br><br>Index of viable system options (no. of viable options per decision implemented) #O07 |
| **security** | Degree of financial, political, social stability #O01<br><br>Success rate in achieving long-term goals #O10<br><br>Percent of government projects that have to be changed or abandoned because of changing conditions #O02 | Degree of internal and external security: people killed per year (per 100,000) by terrorism, crime, social unrest, war #L21<br><br>Percent of crimes leading to solution and conviction #O11<br><br>Rate of change of key environmental indicators #B05<br><br>Degree of internal social stability #L22 |
| **adaptability** | Average multiple qualifications of administrators #O14<br><br>Degree of decentralized responsibility (subsidiarity) #O21<br><br>Average time for institutional change (law, institutions, infrastructure) #O17 | Average period of major political change in country #O27<br><br>Innovative programs introduced and completed by government and administration #O29 |
| **coexistence** | Percent of international partners with similar views and interests #D07<br><br>Percent of population politically active at all levels of self-government and NGOs #O24<br><br>Percent agreement of legal system with interests of other regions, natural systems and future #N05 | Protection of health and rights of individual, nature, future generations in basic law #N01<br><br>Problem solving time (problem stock vs. rate of problem solving) #O08<br><br>Trade partner disparity index #D08 |
| **psychological needs** | Political alienation (percent of population identifying with forces in power) #P13<br><br>Agreement of political form of government with cultural and social norms #P14 | Anxiety related to government and administration (percent of population seeing serious problem) #P05<br><br>Political alienation (percent of people identifying with political forces in power) #P13 |

***Table 13. Indicators of sustainable development for the infrastructure system of a global region.***

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **existence** | Rate of change of per capita service capacity (roads, schools, hospitals, and so on) (expansion or deterioration rate) #L20<br>Security of fixed cost and upkeep financing for next 20 years #F04 | Percent of population with access to clean water and sanitation #L13<br>Percent of population within one hour of all essential services #L12<br>Avoidable mortality and disability as fraction of total mortality and disability #L30<br>Domestic food production rate vs. food demand #D03<br>Food calorie supply per capita as percent of minimum daily adult requirement, for poorest population #L08<br>Rate of change in the number of persistent chemicals in the environment #B14 |
| **effectiveness** | Payback years of capital stock (capital stock/output rate) #F06<br>(Annual cost of education)/(total production rate) #Q02<br>Commercialization depth of transformation chain for essential products: price ratio #F15<br>Powered vehicle kilometres per capita per year #M15<br>Walking and cycling distance per capita per day #L18<br>Expenditures for maintenance of capital stock/value of capital stock #F03<br>Social service unit cost per capita #L22<br>Resource throughput per capita #M01<br>Telecommunication links per capita #O20 | Lifetime fraction required to reach essential services (transportation, waiting, way to work) #L25<br>Average transportation distance for key resources #M16<br>Cost of individual education (time and money) for given qualification vs. lifetime earnings #Q03<br>Creative products (patents, books, art, music) per 100,000 people per year #O31 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **freedom of action** | Average lifetime of infrastructure capital #F05<br>Diversity factor for essential food, transportation, education, health care #M18<br>Potentially available uncommitted funds as fraction of total budget #O04<br>Qualification level of employees and management #Q12<br>Percent of population living in cities of more than 50,000 people #L14 | Average number of options for particular services (shopping, schools, hospitals) #M18<br>Ecosystem encroachment by by infrastructure: road and traffic density #B08<br>Systemic need for transportation system: percent of economy dependent on non-local transport #M17<br>Life expectancy at birth #L06<br>Floor area per person #L17<br>Ratio of average house price to annual income #L16<br>Lifetime fraction required to reach essential services #L25 |
| **security** | Redundancy factor of essential infrastructure services #M19<br>Child mortality #L05<br>Avoidable mortality and disability as fraction of total mortality and disability #L30 | Avoidable mortality and disability as fraction of total mortality and disability #L30<br>Rate of change of key environmental indicators #B05 |
| **adaptability** | Average time for institutional change #O17<br>Average skills and qualifications per person (years in education and training) #Q07<br>(Investment rate in education)/ (investment rate in production capital) #Q01<br>Level of institutional bureaucracy (bureaucrats per working adult) #O15 | Spectrum of future societal options provided by infrastructural solutions #M20<br>(Net population growth rate)/ (net infrastructure growth rate) #L03<br>Rate of change quality lifetime (education, health care, transport, communication) #L29<br>Rate of change of ecological diversity index #B10 |
| **coexistence** | Rate of change of key environmental indicators #B05<br>Ecological footprint vs. permissible sustainable footprint #B01<br>Rate of change of ecological footprint #B02 | Fraction of intact ecosystems #B06<br>Environmental footprint vs. permissible sustainable footprint #B01<br>Rate of change of environmental footprint #B02 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| | Rate of foreclosure of important options #B30 | Rate of foreclosure of important options #B30<br>Cross-border trade and communication vs. domestic #D09<br>Population density #L01 |
| **psychological needs** | Percent of population within reach of all essential services #L12<br>Dominance of business interests over service ethic #N08 | Anxiety related to infrastructural problems (percent of population seeing serious problem) #P02<br>Percent of population who would rather live elsewhere because of infrastructural shortcomings #P11 |

***Table 14. Indicators of sustainable development for the economic system of a global region.***

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **existence** | Ratio of government or foreign economic subsidies to economic output #F13<br>Percent dependence on resources under external control #D01 | Percent of population below sufficiency level (satisfaction of essential needs) #L11<br>Rate of change of ecological diversity #B10 |
| **effectiveness** | Percent of population with income below sufficiency level #W01<br>Resource consumption and pollution per product or service, related to best technical solution (ecological footprint/minimum footprint) #M02<br>Average lifetime of infrastructure capital #F05 | Percent of individual lifetime required to secure means for sufficient lifestyle #L24<br>Percent of economic output required to counteract detrimental effects of system #B32<br>Rate of change of regional carrying capacity #B26<br>Dependence on depletable resources #M06 |
| **freedom of action** | Average time required to implement major entrepreneurial decision (e.g. small plant) #O18 | No. of viable alternatives of individual to present situation (job, place to live) #Q13 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| | (Savings rate)/(capital depreciation rate) #F07<br>Potentially available uncommitted funds as fraction of total budget #O04<br>Work satisfaction #P09<br>Productivity growth rate #F02 | Surplus of uncommitted financial, organizational, material resources available for alternative approaches #O04<br>Rate of foreclosure of important options (environment, resources, regional development) #B30<br>Economic effort per capita #F01 |
| **security** | Percent dependence of vital supplies (food, water, energy, essential materials) on sources not under regional control #D01<br>Dependence on depletable resources #M06<br>Redundancy: dependence on a few central processes or institutions #O06 | (Average property, savings, insurance)/(annual income rate for sufficiency) = financial cushion of individual #L15<br>Percent of population at poverty level #L11<br>(Food and product stocks)/(rate of consumption) = reserves time constant #M04<br>Rate of change of endangered species list #B12<br>Percent of production, commerce, distribution by domestic organizations #D04 |
| **adaptability** | Percent (major) change of product spectrum per year #O30<br>Free organizational capacity: scientists and planners in future-oriented research and development #O13 | Average skill spectrum and qualification of employees and managers #Q08<br>Viable alternatives of individual to present situation #Q13<br>Percent of workforce self-employed or in small business #O22 |
| **coexistence** | Environmental and societal impact: ratio of external costs of economic operations to value of economic transactions (GDP) #F12 | Fraction of controversial economic activity (environmental, resource, economic and social problems, human rights, ethics) (national and international protest) #N09<br>Rate of change of primary production claimed for human use #B09<br>Ratio of actual per capita material consumption to sufficient consumption #L10 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **psychological needs** | Percent agreement of operating principles with ethical principles of regional culture #N04 | Anxiety related to problems of the economic system (poverty, unemployment) (percent of population seeing serious problem) #P01 |

***Table 15. Indicators of sustainable development for resources and environment of a global region.***

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **existence** | Rate of change of key environmental indicators #B05<br>Domestic resource life time: (depletable resources vs. depletable resource use rate) #M08<br>(Renewable resource use rate)/(renewable resource regeneration rate) #M07<br>Threatened species as percent of native species #B11<br>Actual carrying capacity vs. utilized carrying capacity #B25 | Percent of regional carrying capacity used at current lifestyle #M05<br>Percent of resource supply, recycling, regeneration, waste absorption functions which must be supplied by technical means #B21 |
| **effectiveness** | Dependence on depletable resources, renewable energy fraction #M06<br>Percentage of intact ecosystems #B06<br>Energy required to extract one unit of nonrenewable energy #M11<br>Rate of change of energy required to extract one unit of nonrenewable energy #M12<br>Energy required to harvest one unit of renewable resource #M09<br>Rate of change of energy required to harvest one unit of renewable resource #M10<br>Resource throughput per capita #M01<br>Net greenhouse gas emissions per economic output #B04 | Energy cost as fraction of total system operating cost: encouragement of efficient energy use #M03<br>Average transportation distance for key resources (water, energy, food, materials) #M16 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| **freedom of action** | (Renewable resource use rate)/(renewable resource regeneration rate) #M07<br>(Depletable resource supplies)/(depletable resource use rate) = resource life #M08<br>Buffer capacity vs. utilized reserves #B20 | Supply redundancy (for water, energy, food) (percent that could be supplied from alternate sources) #M14<br>Renewable resource use rate vs. renewable resource regeneration rate #M07<br>Net population growth rate #L02 |
| **security** | Environmental footprint vs. permissible footprint #B01<br>Rate of change of environmental footprint #B02<br>(Rate of production or import of key chemicals)/(rate of absorption) #B15<br>Closeness to collapse (eutrophication, erosion, resource exhaustion, overuse) #B28 | Percent dependence of vital supplies on sources not under regional control #D01<br>Supply redundancy of vital supplies #M14<br>Depletable resource life time (resource supplies vs. resource use rate) #M08<br>Net renewable resource depletion rate #B19<br>Percent area used for sustainable agriculture #B22<br>Rate of increase in biocide-resistant species #B13 |
| **adaptability** | (Rate of development of renewable substitutes)/(rate of depletion of nonrenewables) #M13<br>Adaptability limit of key ecosystems #B29<br>Rate of change of ecological diversity index #M10<br>Percent of local adaptation of resource use methods to local conditions #B23 | Percent of infrastructure which cannot be converted to different resource base in less than 10 years #O16<br>Diversity and multiple use capability of environment and resource base #B24<br>Rate of change in the number of persistent chemicals in the environment #B14<br>Percent of unpolluted stream and beach kilometres #B16 |
| **coexistence** | Rate of change of intact ecosystem area (wilderness) #B07<br>Rate of change of ecological diversity index #B10<br>Future discount applied in policy decisions #N03 | Percent of environmental and resource use loads dependent on net uncompensated use of international commons (atmosphere, hydrosphere, soils) #D05 |

| orientor | subsystem performance | contribution to total system |
|---|---|---|
| | | Net rate of accumulation of persistent pollution #B15<br>Rate of depletion of nonrenewable resources #B18<br>Net air and water pollution import or export #D06<br>Loss of fertile soil (fertile area lost vs. original fertile area) #B17 |
| **psychological needs** | Fraction of population with cooperative vs. competitive orientation #N07<br>Regional landscape esthetics #P16 | Anxiety related to resources, environment and future (percent of population seeing serious problem) #P06<br>Percent of population who would escape to another region for the sake of their children's future #P12 |

# 7. Summary, conclusions, outlook

Sustainable development is a particular type of development that is characterized by certain criteria. These criteria of sustainability and evolutionary development can be clearly specified. They provide particular orientations to the systems and actors that are part of the development, causing them to prefer certain actions, paths and impacts compared with others. For assessing progress and actual or expected consequences of actions, the actors need a comprehensive set of indicators describing the state of the systems under their care and of their environment.

The search for appropriate indicators of sustainable development has been going on for many years at many different levels of societal organization: small community, city, region, country and the world as a whole. There seems to be general agreement that a single indicator of sustainable development cannot be defined, and that a substantial number of indicators is necessary to capture all important aspects of sustainable development in a particular application. However, defining an appropriate set of indicators for sustainable development turns out to be a difficult task. If too few indicators are monitored, crucially important developments may escape attention. If a large number of indicators has to be watched, data acquisition and data analysis may become prohibitively expensive and time consuming. Obviously, practical schemes cannot include indicators for everything. It is essential to define a set of representative indicators that provide a comprehensive description—as many as essential, but no more. But what are the essential indicators?

In the past, this problem has mostly been solved by the intuitive assessment of experts familiar with their particular discipline; for example, economics, ecology, sociology and engineering. Corresponding indicator sets are usually characterized by specific disciplinary biases, with gaping holes of oversight in some critical areas, and overly dense indicator specifications in others.

A different system-based approach has been described in this book. Sustainable development is seen as a coevolutionary process of interacting systems in a common environment, where each system follows its own path of self-organization in response to the challenges of its particular environment. The complex web of interacting systems can then be broken down recursively into a network of individual systems, each of them affecting its own fate, and that of another system. Indicators then have to be found that describe the performance of the individual system and its contribution to the performance of the other system. A first task in the search for a proper indicator set consists of identifying the essential systems and subsystems, and analyzing and defining the relevant system structure. Obviously, a considerable amount of aggregation and condensation is required at this point to keep the project within manageable dimensions.

The next step demands finding essential indicators for the performance of each system and its contribution to another system. Following orientation theory, it has been argued here that the essential indicators are those that provide a complete description of the state of satisfaction of the fundamental interests of each system, i.e. its basic orientors: existence, effectiveness, freedom of action, security, adaptability, coexistence and psychological needs (for humans and for systems with humans as components). This leads to the selection of a comprehensive but minimum set of indicators providing information about all essential aspects of viability and sustainability (applying the check list of Table 4).

For each of the slots in the check list of Table 4, it will usually be possible to find a number of relevant indicators. Sometimes it may even be necessary to define a set of indicators corresponding to a hierarchy of orientors (see Sec. 5.3). Methods such as aggregation, condensation, identifying weakest links, taking averages, or choosing a representative indicator to stand for a whole range of similar developments will have to be used to keep the number of indicators down without losing essential information. Also, it is advisable to concentrate on indicator ratios that compare the rate of system response with the rate of threat, giving early warning where processes are threatening to overwhelm the defensive responses of a system.

The approach outlined in Sections 1 to 5 has been applied in Section 6 to define indicator sets for sustainable development at several levels: global, country, state or region and city. Using Worldwatch Institute time series from 1950 to 2000, it was demonstrated how indicator measurements can be translated to a formal assessment of basic orientor satisfaction, and hence system viability and sustainability, and how the results can be presented in graphic form as orientor stars. The results show some disturbing trends.

From the many applications to date it can be concluded that a systems approach using orientor concepts can be a very useful tool not only for defining comprehensive indicator sets for sustainable development, but also for checking existing sets for completeness in the mathematical sense of covering all essential aspects and possible redundancy. It provides systematic guidance for a comprehensive indicator search, thus minimizing the danger of overlooking essential areas or overemphasizing others.

In contrast with indicator sets developed by various *ad hoc* methods, indicator sets derived by the orientor-based approach provide answers to a very specific set of questions (Table 4) covering all essential aspects of viability and sustainable development. This has an important consequence: if all those questions can be truthfully answered in the affirmative, the respective system is viable and sustainable and contributes to the viability and sustainability of the affected system. These answers would not have to come from costly and time-consuming measurements of individual indicators; they could also come from the informed judgment of people familiar with the particular system. The unavailability of data, or of funds to collect more data, is not always a good excuse for not making a sustainability assessment. In particular, the check list of Table 4 can help to guide sustainability assessments that have to be completed under severe constraints of time and funds. Often it will become obvious that a question on the check list can be answered reliably by some simple indicator instead of sophisticated data that may be difficult to obtain and to analyze.

It is suggested that the orientor-based approach of indicator selection should be applied retroactively to validate already existing indicator systems, in particular those that are to be used in large-scale international ventures. It may well be that such validation will only confirm the indicator set, as seems to be the case for the Seattle indicators (see Sec. 6.3). But since all of the sets in current use have been derived without a solid systems-theoretical framework, such an orientor-based validation attempt would probably lead to further improvements of the indicator set in question.

The orientor-based approach of indicator selection will also make the search process much more meaningful for the various indicator initiatives working or beginning to work in the field. It means that their efforts would first have to concentrate on developing an orientor hierarchy for a specific system in its specific environment, moving down from the basic orientors. Indicators would then have to be selected to correspond to the orientors on the lowest level of the orientor hierarchy, i.e., closest to reality. The orientor hierarchy encompasses a holistic system understanding as well as the values and visions of the group. This approach makes it highly unlikely that important aspects will be overlooked, and it also makes obvious any attempt of particular stakeholders to bias the indicator selection in their favour.

In a broader context, regarding indicators as reflections of fundamental interests (basic orientors) of all participants and affected systems puts a solid foundation under the search for indicator sets and removes much of the arbitrariness implicit in current and proposed indicator sets. It turns the focus from an uncertain *ad hoc* search and bargaining process to a much more systematic procedure with a clear goal: to find indicators representing *all* important aspects of sustainable development.

The orientor-based method will affect the selection and application of indicators for sustainable development in the following different domains:

- In the *technical domain* it provides a framework and guidelines for constructing comprehensive and reliable indicator sets.
- In the *capacity domain* it focuses data collection on essential data and minimizes unproductive collection, processing and dissemination of irrelevant or redundant data.
- In the *institutional domain* it provides a common framework facilitating the collection and exchange of data and experience between permanent and networked agencies.
- In the *public domain* it assists in developing the ability of the public, of administrations and of business to correctly interpret and use indicator sets for sustainable development.

# Notes

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32 See also next section.

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# Indicators for Sustainable Development: Theory, method, applications

What do we mean by sustainable development and how do we know if we are unsustainable? How can we tell if we are making progress?

"If you don't use a system-based approach, you are running the risk of collecting a lot of useless information at great cost, while remaining ignorant of the indicators that are really important!" — Dr. Hartmut Bossel

In *Indicators for Sustainable Development*, Dr. Bossel, an engineer and leading systems scientist, shows that we need indicators for sustainable development that provide reliable information about the natural, physical and social world in which we live, and on which our survival and quality of life depend. He illustrates that popular indicators like the gross domestic product are inadequate, as they inform us only about monetary flows and not about the state of the environment, the destruction of resources or the quality of life.

The former professor of environmental systems analysis and director of the Center for Environmental Systems Research of the University of Kassel, Germany summarizes a systems approach for finding indicators of sustainable development, and applies this approach to finding indicator sets for communities, states, countries and the world. He shares the theoretical foundations, the implementation procedure and the practical experience, providing several complete lists of indicators of sustainable development for different regions.

Indicators for Sustainable Development: Theory, Method, Applications. 4.5. The horizon of attention Essential systems and multidimensional viability: the need for many indicators Looking for the weakest links Comparable results of sustainability assessments despite subjective choice The horizon of attention defines indicator selection Indicator selection can be independent of ideology.Â Identifying representative indicators Recursive scheme for finding indicators of viability Reducing the number of indicators to a manageable set Adding detail: orientor hierarchies Systematic approach to asking the relevant questions Other criteria for indicators of sustainable development 5.4.