Global Journal of human-social science: B
Geography, Geo-Sciences, Environmental Disaster Management
Volume 14 Issue 1 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-460X & Print ISSN: 0975-587X

Towards Systematic Framework for Sustainability

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Abstract- A systematic framework of indicators for sustainability is presented. In our approach there is an emphasis on societal activities that affect nature and on the internal societal resource use. In this way the indicators may give a warning signal to an unsustainable use of resources early in the chain from causes in societal activities to environmental effects. The aim is that socio-ecological indicators shall serve as a tool in planning and decision-making processes at various levels in society. The formulation of the indicators is made with respect to four principles of sustainability, which lead to four complementary sets of indicators.

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GJHSS-B Classification : FOR Code: 909899

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I. Introduction

The publication of the Brundlandt report 'Our Common Future' (WCED, 1987) and the Rio Declaration (United Nations, 1992a) put the challenge of sustainable development on the agenda for planners, decision makers and politicians at all administrative and institutional levels of the global society. Since then, much effort has been made to define and operationalise the concept of sustainabilily.

Many researchers have suggested various types of non-monetary measures to indicate to what extent environmental slates and functions, material flows, or societal activities can be regarded as sustainable (see, e.g., Vos et al., 1985; Liverman el al., 1988; Kuik and Verbruggen, 1991; Opschoor and Reijnders, 1991; Holmberg and Karlsson, 1992; Adriaanse, 1993; Alfsen and Saeb0, 1993; Bergstrom, 1993; Gilbert and Feenstra, 1994; Moffatt, 1994; OECD, 1994). Most sets of indicators developed so far have focused on the state of the environment rather than on the relation between society and ecosystems. In the present paper we formulate indicators based on four socio-ecological principles for sustainability (Holmberg et al., 1996). The principlesand, hence, the indicators focus early in the causal chain—i.e., in the chain of causes in society to effects in the environment. In this way socio-ecological indicators may give an earlier warning than would environmental quality indicators.

There are two aspects that are important in the construction of our indicators:

(i) There are in many cases long time delays between a specific activity and the corresponding environmental damage. This means that indicators based on the environmental state may give a warning too late, and in many cases only indicate whether past societal activities were sustainable or not.

(ii) The complexity of the ecosystems makes it impossible to predict all possible effects of a certain societal activity. Some damages are well-known, but others have not yet been identified. Most of the sustainability indicators suggested so far are formulated with respect to known effects in the environment. We suggest that indicators of sustainability should be formulated with respect to general principles or conditions of sustainability.

The socio-ecological principles that form the basis of the socio-ecological indicators focus on the societal activities and interactions with nature and internal societal resource use. The first principle deals with societal use of elements from the lithosphere. The second principle deals with the necessary restrictions on emissions of anthropogenically produced substances. The third principle concerns the anthropogenic manipulation of nature. Finally, the fourth principle deals with the efficiency of the societal resource use. These principles have in common that they are formulated in terms of societal activities.

We use these four principles as a systematic framework for developing indicators. Our aim is then to define indicators that are based on data that reflect societal activities rather than the slate of the environment. In the present paper we exemplify the four different types of indicators by calculating their values using mainly global data.

In Section 2, we discuss various approaches that have been made to indicate sustainability. In Section 3, the four socio-ecological principles for sustainability are reviewed. Then, in Section 4, we develop a set of indicators for each of the four principles. Numerical estimates of these indicators are also presented. Section 5 is devoted to a discussion of the results and on areas for future research.

II. Indicators for Sustainability

There are both monetary and physical approaches lo indicating sustainability. In this paper we focus on physical indicators. Such indicators can be divided into three (main) groups: (i) societal activity indicators (that indicate activities occurring within

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society—the use of extracted minerals, the production of toxic chemicals, recycling of material), (ii) environmental pressure indicators (that indicate human activities that will directly influence the state of the environment—e.g., emission rates of toxic substances) and (iii) indicators of the state of the environment or environmental quality indicators (that indicate the state of the environment—e.g., the concentration of heavy metals in soils and pH levels in lakes).

It should be noted that most indicators for sustainability developed and used so far belong either to the group of environmental pressure indicators or to me state of the environment indicators. This is shown in Table 1 where we have illustrated where some authors have put their focus when developing and evaluating indicators for sustainability.

III. Principles of Sustainability

In our formulation of indicators for sustainability we use a framework of principles that should be fulfilled in a sustainable society (see Holmberg et al., 1996). The principles are presented below.

Table 1 : The focus of some indicators for sustainability

Reference	Indicated area	Societal activities	Environmental pressure	State of the environment
Adriaanse (1993)	The Netherlands	x	x	
Alfsen and Saebo(1993)	Norway			x
Ayres(l995)	Mainly USA	x	x	
ten Brink (1991)	Specific ecosystem			x
Brown etal. (1994)	The world	x	(x)	(x)
Carison(1994)	Sweden	x	x	
ECE (1985)	ECE member countries	(x)	x	x
Environment Canada (1991)	Canada		x	x
Gilbert and Feenstra(1994)	Specific ecosystem		(x)	x
Holdren(l990)	The world		x	(x)
Holmberg and Karlsson (1992)	Not specific	x	x	
Milj0minisleriet (1991)	Denmark.	(x)	x	x
Nilsson and Bergstorm (1995)	Municipality and company	x	x	x
OECD (1994)	OECD countries	(x)	x	(x)
Opschoor and Reijnders (1991)	Not specific		x	x
SNV (1994)	Sweden			x
Haesetal. (1991)	Specific ecosystem			x
Vos etal. (1985)	The Netherlands		x	x
This paper	The world	x	x	

The symbol 'x' indicates the main focus of the work, while (x) means that such indicators are included, but only play a minor role in the work.

a) *Principle 1: substances extracted from the lithosphere must not systematically accumulate in the ecosphere.*

Elements from the lithosphere must not be spread at a rate which will give rise to a systematic increase in the ecosphere. Such an increase will occur if the sum of the anthropogenic emissions and the natural flows from the lithosphere to the ecosphere (weathering processes and volcanic eruptions) exceeds the sedimentation rate and the rate of final disposal in the lithosphere. Because of the complexity and delay mechanisms of processes in the ecosphere, it is extremely hard to say what level of accumulation will cause an effect. In fact, every substance has a limit (often unknown), above which damage occurs in the ecosphere. Increasing amounts of carbon dioxide in the atmosphere, of sulphur dioxide leading to acid rain, of phosphorus in lakes and of heavy metals in soils and in our bodies are all examples of such accumulation. In practice, this principle implies restrictions on the extraction rate of metals and fossil fuels in combination with increased recycling of material and decreased dissipative use of scarce elements. It also implies substitution of abundant elements for scarce elements.

b) *Principle 2: society-produced substances must not systematically accumulate in the ecosphere.*

In the technosphere, molecules and atomic nuclei of different kinds are produced, some of them long-lived, in amounts previously unknown to the ecosphere. If they are emitted faster than they are degraded into molecules or nuclides that can be integrated in the ecospheric cycles, and/or faster than they are removed to the lithosphere, such substances will accumulate in the ecosphere. In order to reduce the amount emitted, one can degrade substances within the technosphere or deposit them in final disposals. CFC molecules destroying the ozone layer, increasing amounts of DOT and PCB in biota, and radioactive inert gases in the atmosphere are all examples of such accumulation. The principle also implies that persistence is a very important aspect of substances that are foreign to nature, and therefore there should be strong restrictions on the use of persistent substances foreign to nature.

Finally, we notethat higher concentrations in the ecosphere may lead to increased sedimentation rates (for Principles 1 and 2) and/or higher degradation rates (for Principle 2) so that a new equilibrium concentration may be established.

c) Principle 3: the physical conditions for production and diversity within the ecosphere must not become systematically deteriorated.

A sustainable society must not systematically reduce the physical conditions for the long-term production capacity in the ecosphere or the diversity of the biosphere. Society must neither take more resources from the ecosphere than are regenerated nor systematically reduce natural productivity or diversity by manipulating natural systems. Deforestation, soil erosion, land degradation with desertification as an extreme form, extinction of species of plants or animals, exploitation of productive land for asphalt roads and refuse dumps, and destruction of freshwater supplies are examples of such reduction.

Society is dependent on the long-term functions of the ecosystems. Even if Principle I and Principle 2 are fulfilled, society must be careful with its manipulation of the resource base in order to avoid a loss of the productive capacity for the supply of food, raw materials and fuel. This dependence will become more obvious when the use of fossil fuels is reduced (in accordance with Principle I).

d) Principle 4: the use of resources must be efficient and just with respect to meeting human needs.

Principles 1, 2 and 3 constitute the external conditions for a sustainable metabolism of a society. The assimilative capacity as well as the available resource flows are limited. In order to fulfill human needs for a growing global population, the resources and services obtained from nature must be used efficiently within the society. Socially, efficiency means that resources should be used where they are needed most. This also leads to the requirement of a just distribution of resources among human societies and human beings.

IV. Indicator Frameworks for Sustainability Evaluation

a) Background to sustainability indicators

The main thrust for sustainability indicators for renewable natural resource management and in agriculture and rural development in particular has its origins in the sustainable development paradigm. The widespread "adoption" or pursuit of sustainable development, and indicators of sustainability, took off following the Earth Summit in Rio in 1992. Agenda 21 called for the development of, amongst many things, sustainable agriculture and land management as well as the systems necessary to monitor their achievement. This has led to a wide range of activities which have sought to define sustainability and, of particular relevance to sustainable agriculture, land management and forestry (Pretty, 1995 for comments on the number of different definitions since the Brundtland Commission (WCED, 1987)). FAO have developed 40 methodology sheets on how to calculate indicators in the areas of agriculture, biological diversity, desertification, fisheries, forestry, freshwater, land use, and mountain ecosystems. Basher (1996) states that currently there isno general agreement on appropriate indicators and many countries are in the process of establishing environmental monitoring networks and testing potential environmental indicators (e.g. Kerr, 1990; Messer etal., 1991; Hamblin, 1992; Doran etal., 1994).

Most, if not all, of these initiatives have been technically led, and have tended to focus on a natural science view of sustainability and associated issues. The Framework for the Evaluation of Sustainable Land Management (FESLM, Smyth and Dumanski, 1993) has, for example, been developed from a technical land management or soil science starting point. Alternative approaches have focussed on community indicators identified through participatory approaches. These have included the International Institute for Sustainable Development, USD, programme on Community Adaptation and Sustainable Livelihoods, CASL, in sub-Saharan Africa, and an IIED project in Brazil on participatory monitoring and output assessment of sustainable agriculture (Sidersky and Guijt, 1997). In relation to desertification, a workshop was held on the grassroots identification of sustainability indicators as early as 1992 (Hambly and OnwengAngura, 1995).

The paper focuses on some of the most relevant issues with respect to development of indicators of sustainable systems. After a very brief explanation of indicators and thresholds, issues of time and scale are highlighted, different frameworks for organising indicator work are discussed and the different dimensions ofAagricultural sustainability commonly identified are outlined.

b) Indicators and Thresholds

Smyth and Dumanski (1993) define indicators as "environmental attributes that measure or reflect environmental status or condition of change", Glen and Pannell (1998) argue that "an indicator is a quantitative measure against which some aspect or aspects of policy performance or management strategy can be assessed". This criterion of quantification assigned by many authors is not universally accepted, sincesome authors regard qualitative indicators (e.g. visual assessment of soil erosion) as valid tools.

Definitions are numerous, and it is perhaps more useful to identify the uses and desirable properties of indicators. Following Tunstall (1992, 1994), Gallopin (1997) identifies major functions of indicators as:

- to assess conditions and changes;
- to compare across place and situations;
- to assess conditions and trends in relation to goals and targets;
- to provide early warning information; and,
- to anticipate future conditions and trends

A developing issue highlighted by several authors including Syersetai(1995) and Coughlan (1996) is the importance of defining thresholds for indicators. A threshold is a boundary level of a variable which is regarded on the basis of expertise to represent the point at which significant changes occur. "Thresholds are particularly important in an agri-environmental context given the propensity of ecological systems to 'flip' from one state to another" (Moxey, 1998: 14).

When an indicator passes this level then the system is considered to be unsustainable or on the road to unsustainability. Issues arise as to the identification of a threshold level (be it qualitative or quantitative), whether passing a threshold level for one indicator is sufficient to signify unsustainability, or whether several indicators need to have passed their threshold levels before the system is unsustainable.

c) *Issues of Scale*

The type of indicators constructed in any study will be influenced by the level at which the system is analysed. Indicators in studies such as this may be constructed at the plot, farm, village or community, district, catchment, region, agro-ecological zone (AEZ), or national level. For instance, the individual farmer will often be seeking, or will already have identified, an indicator which forecasts the yield of this year's crop based on a field or farm plot scale. Again at the farm level, the depth of soil may be a key indicator in assessing the sustainability, but at the national level it is impractical to measure the depth of all soils when it comes to assessing the agricultural systems at the national scale. Alternative or broader indicators are needed to achieve this. However, there has to be a link between the different levels. If we are using indicators to assess the relative sustainability of different farming systems we need to be able to relate this information and analysis to assessments at a "higher" level.

The decision about the level at which to collect information and apply indicators depends on both the issues being addressed and the data available. However as one moves up through the levels it may become more difficult to identify causal relationships, to identify desirable outcomes and to isolate choices that can be made with confidence. The level at which, indicators are constructed has implications for the type of indicators that it is feasible to construct. Gomez el al. (1996) argue that working at the farm-level means that social issues cannot be incorporated, whilst Muller (1996,1998) excludes social issues at the plot level but includes them at the farm household level.

There is no prescription here regarding what is the appropriate level of measurement of indicators for this study. The project's emphasis on the investment decisions of farm households of differing scales and success indicate that the farm/farm household are likely to be the focus of attention, but probably not to the exclusion of assessment at the plot as well as higher levels of scale (village, region). The different types of indicator are likely to occur at different levels of scale. However, we expect, the measurement of certain types of indicator (see, for example, driving force or pressure indicators - section 3.6.2) to take place at levels above that of the farm household. So driving forces and pressures in the region (population change, increasing competition for land etc.) will shape the livelihood strategies of individual households.

This issue of scale should be borne in mind throughout the development of this study's indicator sets.

d) *Internal and External Indicators*

A central issue of the research is the identification of suitable indicators. A key question behind this is who identifies the indicators and on what basis. It is useful to identify two sets of indicators: those identified by "external" experts, such as the project researchers; and, those "internally" identified by the different stakeholders in the systems themselves. The latter group would include farmers, households, communities, and local agencies (e.g. District office of Dept of Agriculture, or NGOs). When considering this division between the role of "external" researchers and local "community" members, it is worth noting that there is also a separation here between issues and indicators. A key issue in the success or otherwise of a system (for example, the maintenance of soil fertility) may be agreed upon by both researchers and community members. However the indicator which each group uses to monitor the issue may differ. Alternatively, it may be the case that the key criteria on which the success or failure of the system is judged differs between researchers and community members, in this case the both the key issues identified (and the associated indicators) are likely to be different.

e) *Cross-section or Time-Series Analysis (Stale or Rate)*

A major issue to be decided upon here is whether indicators are to be constructed and monitored between sites at a single point in time, monitored over time, or both. Ideally indicators of both types will be measured.

Given the nature of this project, with its focus on the issue of farm size for example, the comparison between different sites is central.

A fundamental issue is time. We want to know what has and is changing. What has happened to the biophysical environment, how have people's perceptions and management and livelihood strategies changed, how have policies and institutions changed and how have these affected each other? However, monitoring over time is more problematic, as information from external sources is generally required.

If trends over time are to be determined then there are two relevant alternative sources of information:

1. Historical sources which may include:
   - Secondary historical information - past records; studies and surveys.
   - Community and individual recollection.
2. Biophysical information from sites which were previously of a similar type to other study sites, but have been cultivated or otherwise used in a different manner over a recent, known time-period. In this way measurements taken at the same moment in time can be treated as observations at differing time points. In this way, a baseline site can be paired with other sites.

f) Indicator Frameworks

Several sets of methodological frameworks or guidelines have been identified for the measurement of sustainability indicators at the farm or community to district levels. These have all tended to come from an approach focussed on sustainable agriculture and/or sustainable land management - often directly related to the FESLM. These have included: the guidelines for conducting case studies under the FESLM (Dumanski, 1995); Protocol for conducting case studies under the FESLM (Bechstedt and Renaud, 1996); and Guidelines for Impact Monitoring (CDE). Other relevant frameworks are those on sustainable livelihoods and poverty assessments. For example, UNDP is also developing a framework for poverty assessment and associated indicators (UNDP, 1999).

The United Nations, World Bank, OECD, European Environment Agency (EEA), IBSRAM and many other organisations and national governments are currently producing indicators or proposed indicators of sustainable development and sustainable agriculture. The frameworks within which these methodologies and indicators are being proposed differ. Some are developments of previous frameworks, but their frequent use is a recognition that a conceptual framework is required to organise indicators.

In addition to the various frameworks used, there are differing dimensions, aspects or properties of sustainable agricultural systems that are proposed as criteria for sustainability assessment.

Pressure-State-Response Framework

The PSR framework, illustrated in Figure 1 and Figure 2 was developed from the stress-response framework which was applied by Friend and Rapport (1979) to ecosystems. This framework is used by OECD, SCOPE (Scientific Committee on Problems of the Environment) and some other organisations working in the field. The PSR framework is the most widely accepted of the many frameworks advocated (Jesinghaus, 1998). Having been adopted by the OECD for its State of the Environment (SoE) group, the European Commission's indicator development also uses the PSR approach. The PSR framework is also used in the methodology of theWorld Bank's Land Quality Indicator (LQI) programme which makes use of the 5 Pillars of Sustainable Land Management (discussed below).

Pressure refers to "human activities that exert a pressure on the environment and change its quality and the quality and quantity of natural resources (the 'state'). Society responds to the changes through environmental, general economic and sectoral policies (the 'response'). The latter forms a feedback loop to pressures." (Gallopin, 1997: 22). These pressures are considered to be negative. An illustration of how the PSR framework might be applied to this study is given in Figure 2.

The OECD acknowledges that the PSR framework has an implicit notion of causality within it since it "tends to suggest linear relationships in the human activity-environment interaction" (OECD: 1993: 5). Unhappiness with this idea that (negative) pressure causes changes in the environment which prompts society's responses is one of the motivations for the development of the driving force-state-response (DSR) framework now discussed.

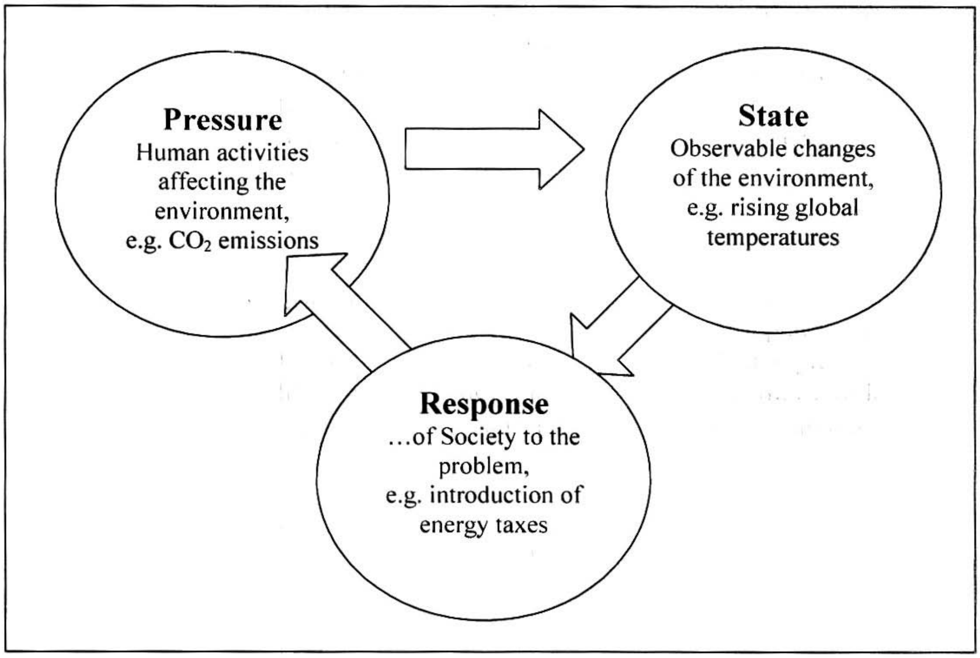

Figure 1 : The PSR Framework

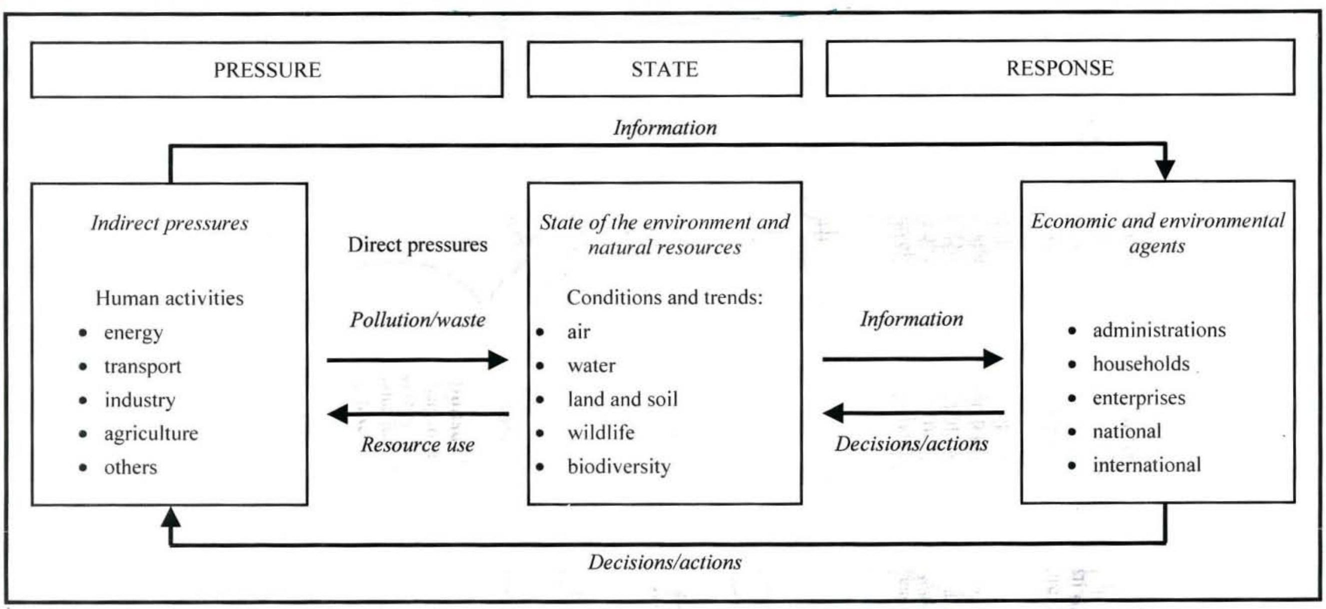

Figure 2 : Pressure - State - Response (PSR) Model

Introducing Driving Forces and Impacts into the PSR Framework

Some organisations prefer variants of the PSR model; for example, the UN Commission for Sustainable Development (UNCSD) bases its indicator set on the Driving force-State-Response model (DSR) model, which allows for a better inclusion of non-environmental variables. The replacement of the term "pressure" in the PSR framework by the term "driving force" was motivated by the desire to include economic, social and institutional aspects of sustainable development.

This adjustment was deemed necessary when one shifts from a consideration of environmental indicators to these indicators plus the state of the human subsystem. (Gallopin, 1997: 22). The extension of the focus to all aspects of sustainable development (social, economic, environmental and institutional) is argued to be "particularly important for developing countriesfor whom an equal balance between the developmental and environmental aspects of sustainable development is important in order to ensure future sustainable growth patterns" (1997: 49).

Another aspect of the DSR framework which separates it from its predecessor is that there is no assumption of causality between indicators in each of the categories."The term 'driving force' indicates...an impact on sustainable development. This impact can be both positive and negative, which is not the case for the pressure category used by the OECD". (Mortensen, 1997: 48-49)."Driving force indicators represent human activities, processes and patterns that have an impact on sustainable development" (Mortensen, 1997: 47).The World Bank has also adopted the DSR framework in its work on indicators of environmentally sustainable development (Pieriet al., 1995), and this has been repeated by other organisations and nations. For a better description of underlying economic trends, some authors have formulated the Driving force-Pressure-State-Impact-Response model, which includes PSR and DSR as special cases (Jesinghaus, 1998).

In the DPSIR frame work State and Impact indicators are separated. State indicators show the current condition of the environment. Examples include the concentration of lead in urban areas; the noise levels near main roads; the global mean temperature. Impact indicators describe the ultimate effects of changes of state. Examples include the percentage of children suffering from lead-induced health problems; the mortality due to noise-induced heart attacks; the number of people starving due to climate-change induced crop losses.

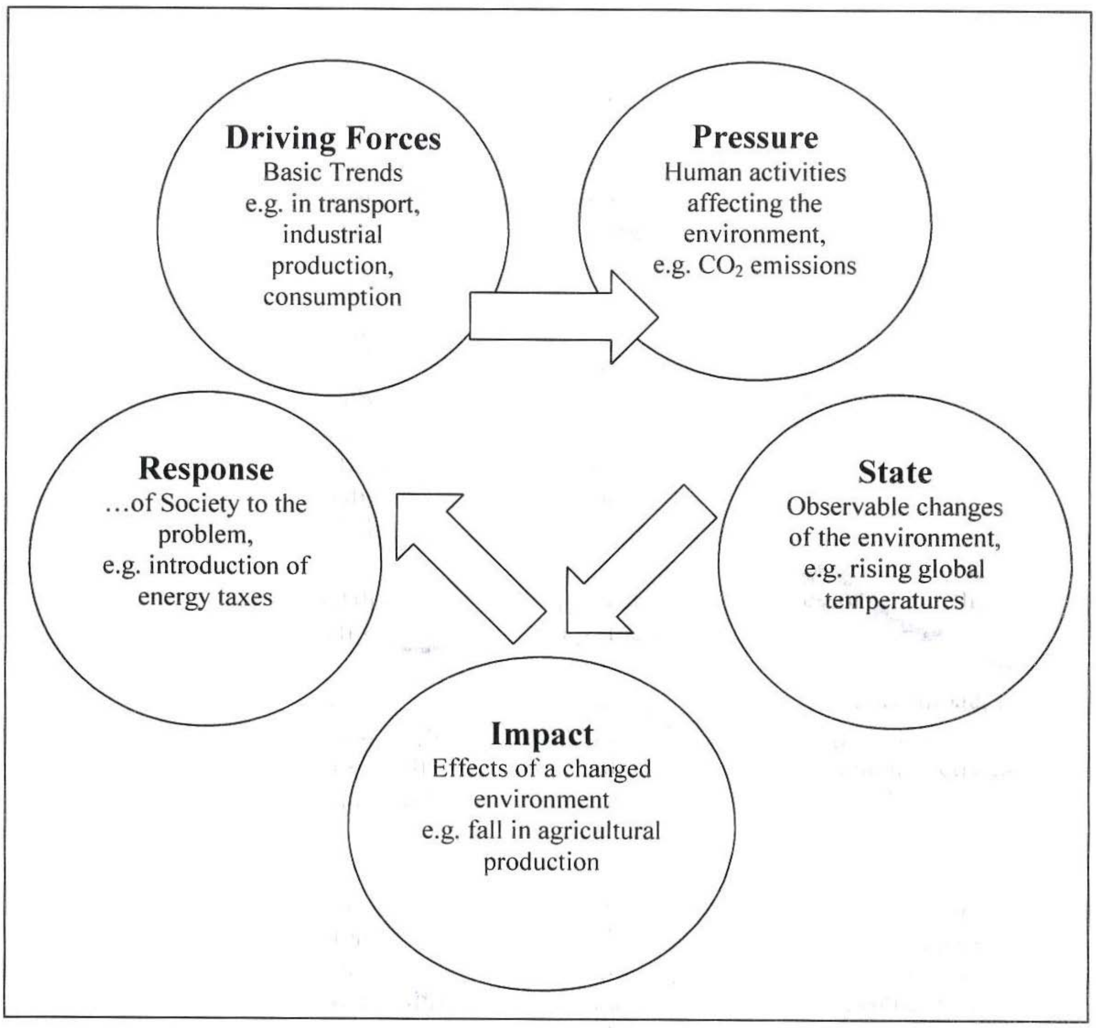

Figure 3 : The DPSIR Framework

V. Currently Used Indicators

a) Gross Domestic Product (GDP)

Gross Domestic Product (GDP) is the market value of all final goods and services produced within a country in a given time period, usually one year. It is usually correlated with the standard of living, which in fact is not true in its entirety. GDP is the basic measure of a country's overall economic output.

b) Determination of GDP

GDP can be determined in three ways. They are the product (or output) approach, the income approach, and the expenditure approach. The 'product approach' sums the outputs of every class of enterprise to arrive at the total. It is used to calculate the market value of goods and services produced in the country. The 'income approach' method measures GDP by adding incomes that firms pay households for the factors of production they hire- wages for labor, interest for capita!, rent for land and profit for entrepreneurship. The last approach to GDP is the 'expenditure approach', which calculates GDP by summing the four possible types of expenditures as follows[1]:

GDP =Consumption + Investment + Government Expenditure + Net exports2

c) Components of GDP

GDP (Y) is the sum of Consumption (C), investment (I), Government Spending (G) and Net Exports (X - M). This is represented in the equation below:

$$GDP(Y) = C + I + G + (X\text{-}M)$$

- *Consumption (C):* it's normally the largest GDP component in the economy, consisting of private (household final consumption expenditure) in the economy. These expenditures fall under one of these categories: durable goods, non-durable goods, and services. E.g. includes rent, food, gasoline, and medical expenses.
- *Investments (I):* Includes business investment in equipment and does not include exchanges of existing assets. E.g. includes the purchase of a software or machinery for a factory. Spending on new houses by households is also included in Investment. However, investment in GDP does not mean purchases of financial products.
- *Government (G):* is the sum of government expenditures on final goods and services. It includes salaries ofpublic servants, purchases of weapons for the military, and any investment expenditure by a government. It does not include any transfer payments, such as social security or unemployment benefits.
- *NET EXPORT (X - M):* Net exports represent gross export minus gross imports. Exports include goods and services produced for other nation's consumption, and therefore exports are added. Imports on the other hand include goods and services produced by other nations and brought into the country and therefore imports are subtracted.

d) Three Limitations of GDP

1. GDP only counts goods and services that pass through the market; Production that is not bought or sold does not generally get counted. For example, if a nomadic or agricultural society is self-sufficient within small groups, there may be considerable production unrecorded in the GDP because none of it reaches the market. This omission also means that a rapid rise in GDP may not reflect more production, but a shift from a non-marketed form to a marketed form.
2. GDP has serious deficiencies as a measure of economic welfare: In the late 1960s several economists decided to adjust GDP (actually GNP, which was the measure then) to obtain a better measure of economic welfare, which they called Measure of Economic Welfare, or MEW. They noted that leisure was valuable, but this value was not recorded in GDP. If people work 60-hour weeks rather than 40-hour weeks, GDP will be higher, but people may be worse off. They also noted that many "bads" are included in OOP-higher crime rates lead to more expenditure on police, international tensions lead to more expenditure on arms, more disease leads to more medical spending. etc.and thus GDP overstates welfare. Further, the production of some goods also brings with it some "bads"pollution is an example.
3. Shadow Economy is not reported in the GDP: The shadow economy, the economic activity unreported to the government, is not accounted for in the GDP. For example when a waitress takes tips that she does not report, or a plumber offers to work for less if paid in cash rather than by cheque or a farmer who sells vegetables at a roadside stand understates his revenues to the IRS, each is part of the shadow economy.
4. Gross Domestic Product still is a widely used index and it the value of everything a country has produced in a period of one year. It is also often used to compare the economic activity of two countries. The change in the gross domestic product is often used to describe the development of a country. GDP is used for the samereason other indicators are used:
   1) To Raise awareness and understanding
   2) To Inform decision-making
   3) To Measure progress towards established goals
5. However, when the environmental issues are contemplated, GDP does not fulfill the aims of an index, as it does not inform the decision-makers of the environmental impact that the GDP has had.

e) Carbon Footprints

According to the website Carbon Footprint™ a carbon footprint is a measure of the impact our activities have on the environment, and in particular climate change. It measures the amount of greenhouse gases produced in people's everyday lives concerning, for example, burning fossil fuels for electricity, heating, and transportation. It is also stated in the website that carbon footprint consists of two parts: primary and secondary. The primary footprint is further explained to be a measure of our direct emissions of CO2 that we can control. These include, for example, domestic energy consumption and transportation. The secondary footprint is stated to be the measure of our indirect emissions from the whole life-cycle of the products we use. Thus, these include all the emissions caused by the manufacturing of the products, and also the waist that they create when breaking down. All in all, the more we buy, the more emissions we cause.[3]

The measurement of carbon footprint is not simple. Wedmann and Minx state that most articles deal with the question of how much carbon dioxide emissions can be allocated to a certain product, company or organization, although none of them provides an unambiguous definition of the term carbon footprint. However, the term is most usually used as a synonym for emissions of carbon dioxide or green house gases expressed in CO2 equivalents.5

f) Ecological Footprint

At the moment people in the world consume so much that we have already exceeded the Earth's ecological potential. In other words, we consume faster that the planet is able to regenerate its resources. Ruzevicius argues that "the growing pressure of ecosystems creates disintegration and distinction of natural habitats, threatens the biological diversity and well-being of humanity"; and the economic and social development in a country should be oriented such way that it doesn't harm the opportunity to satisfy the needs of future generations.

In his article Ruzevicius states that ecological footprint is an indicator that reflects national and global sustainable development. The concept was first created by Mathis Wackernagel and William Rees in 1990. It exists to indicate the effects inhabitants have on their environment and natural resources in a region or a country, i.e. "how much biologically available earth and water resources are consumed and how much of our waste do they absorb". Ruzevicius states that the concept of Ecological Footprint also includes the product's life-cycle analysis. According to him this analysis quantifies product's impact on the environment through its life, including, for example, the energy and material associated with materials extraction, manufacturing, assembly, distribution, use, disposal, and the resulting emissions. For that reason, the carbon footprint discussed above is a part of ecological footprint.

Ecological Footprint is calculated and reported yearly by an international organization called Global Footprint Network. The size of the ecological footprint is determined as follows: "quantity of arable land together with land used for agriculture needed per person or for a group of people in the city who use energy, food, water, transport, waste disposal as well as for people living in buildings with many other needs." The article of Ruzevicius highlights, though, that even though the Ecological Footprint is a good indicator to reflect national and global sustainable development, it is only ah environmental protection index since "it doesn't integrate social and economical indicators that are important while estimating the sustainable development of the country, region or city.

g) Green GDP

The Green GDP is an indicator which was created in China in 2004 by Wen Jiabao premier of China. It replaced the GDP between 2004 and 2006. Its aim is to calculate the GDP of China in taking into account the negative externalities on the environment caused by the economy[5]. Hence, the calculation of the Green GDP is as follows: GDP - Resource and environmental costs.[2]

The advantages:

- It gives us another perspective on GDP, which provides some keys to improve the protection of the environment and deals with the scarcity of resources
- It gives indications to save our future.[6]
- The importance which is given to the environment does not reduce the one of the economic development.[5]
- No preliminary step to calculate it.

The drawbacks:

- How to calculate resources and environmental costs? The consequences of pollution takes several years to appear, so in which year do we must taking them into account.
- Pollution can damage distant areas; nature can improve or worsen the consequences of the pollution.[3]
- China stopped its use because it gave too bad results: With it, the GDP became close to zero.[5] All in all, this new indicator can easily give some useful information on environmental destruction. It also punishes the countries which pollute too much. However, there are still the problem of accounting and the fact that no one would use it because of the bad results it gives. That is why, to be efficient, all the system of values must change to suppress this idea of competition.

h) Human development index (HDI)

The Human Development Index (HDI) has been created in 1990 by the economist AmartyaSen, in order to give information that arenot taken into account in the GDP. Every year, it is calculated by the Program of the United Nations for the development, for 175 countries.[7]

The HDI is the aggregation of three elements: the GDP per capita, the life expectancy and the level of education. Those three components have the same weight in the calculation in order to reduce theinequalities between all the different countries.[9]

Nevertheless, its main drawback is that if one of the component decreases, the increase of another one can balance the loss. Yet, the components are not substitutable. Besides, the HDI is evaluated between 0 and 1 as its elements, so that let to developed countries a very little margin of progress.9Furthermore, this indicator does not take into account any environmental aspects.

i) Happy planet index

The Happy Planet Index shows "the ecological efficiency with which human well-being is delivered around theworld".[10]

It is composed of three parts[11]:

- Life expectancy at birth: it is quite easy to measure (calculation is based on reliable and constantly updated figures: the number of deceases can be obtained on the basis of death certificates, ages, frequencies). It could be an interesting tool to keep.
- Life satisfaction: First, it seems complex and quite subjective to measure. But researchers have found means of quantifying life satisfaction: the size and strength of social networks, relationship status, level of education, presence of disability, material conditions, such as income and employment. It can be useful as long as it is correlated to higher levels of social capital, better climate, richer natural resources, higher life expectancy, andbetter standards of living. Here is a proof that governments may trust it to assess progress (the achievement of human goals): in 2008, the UK Department for Environment, Food and Rural Affairs used it in its set of sustainable development indicators. But you could always add criteria. That is why it might not be the most appropriate tool for our new indicator, at least if we want to have a "transparent" measure.
- Ecological footprint: It can be measured quite easily (measures the amount of land required to provide for all their resource requirements + the amount of vegetated land required to absorb all their CO2 emissions embodied in the products they consume, which is expressed in global hectares). It includes a notion of sustainability. The European statistical agency Eurostat is considering incorporating the ecological footprint into its sustainable indicator set; the Welsh government has already adopted it as one of five indicators of sustainability. It is also useful for understanding social justice. Improving living standards in poorer countries can only be achieved in parallel with declining resource consumption in richer ones.

Therefore it is a pragmatic indicator, providing information about the way countries manage to achieve sustainability in the whole process of their activities, focusing on the input and the output. The input is represented by the resources from the environment and the output by the human welfare.[12]

However, there are some limits:

- As it focuses on the input and output, it does not really consider the in-between elements (the operations; economic aspects)
- One of its subcomponents (life satisfaction) is quite subjective to calculate, since you can indefinitely add criteria to assess it.

j) Gross National Happiness

The 4th King of Bhutan, HM Jigme Singye Wangchuck, promulgated GNH since the beginning of his reign in 1972. The fact that he said GDP needed to be channeled towards happiness in 1970s and 1980s was quite new. Since then, GNH has attracted attention, and opinion around the world has started to converge on happiness as a collective goal.[13]

The GNH indicators have been designed to include nine core dimensions that are regarded as components of happiness and well-being in Bhutan, and are constructed of indicators which are robust and informative with respect to each of the dimensions. These nine indicators are-[15]

1. *Psychological Well-being:* It includes the following indicators, general psychological distress indicators, emotional. balance indicators, and spiritually indicators.
2. *Time Use:* In the GNH index, time use component is divided into benchmark indicators of sleeping hours and of total working hours,
3. *Culture:* There are a wide range of indicators such as dialect use indicator, traditional sports indicator, community festival indicator, artisan skill indicator, value transmission indicator, and basic precept indicators
4. *Community vitality:* Community indicatorsare family vitality indicator, safety indicator, reciprocity indicator, trust indicator, social support indicator, socialization indicator, and kinship density indicator
5. *Health:* Three main indicators take place within the health measuring, health status indicator (self-rated health, disabilities, body mass index, and number of healthy days per month); health knowledge indicator (HIV transmission and breast feeding practices); barrier to health indicator (distance to the nearest health facility)
6. *Education:* Education attainment indicator as well as knowledge and skills
7. *Environmental Diversity:* GNH also focus on ecological indicators such as Ecological

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degradation indicator, Ecological knowledge indicator, and afforestation indicator.

8. *Living Standard:* The living standards indicator consists of income indicator, housing indicator, food security indicator, and hardship indicator.
9. *Governance:* Government performance indicator, freedom indicator, and institutional trust indicator.

k) GNH Index Construction

In a first step, there is a comparison between the different districts surveyed, to see which districts have higher GNH scores. After that, GNH is analyzed across time to see if GNH is decreasing or increasing after we conduct future surveys.

The next step is to decompose the GNH by dimension (or indicator), by district, by gender, by occupation, by age group etc., in order to see how shortfalls in GNH vary across disaggregated levels. This information reveals immediately in what dimensions of life shortfalls from sufficiency are most acute. Only once the GNH is decomposed, tracking this decomposition across time is the best way to see in which dimensions sufficiency is increasing or decreasing.

The last step is to study the average severity of deprivations, to identify whether the gap below the sufficiency cutoff is deepening or narrowing across time.[15]

Table 2 : Matrix for sustainability indicators

Dimension s(FESLM)	Assets (SRL)				
	Natural	*Physical*	*Financial*	*Human*	*Social*
Productivity	Levels and trends for: Productivity (per unit of land, per unit of water [irrigated systems])		Levels and trends for: Rates of return on investment [financial outlay]	Total earned income (on-farm and off-farm) per working household member	Active cooperative association-ns, organisations; Government extension services; Labour or asset sharing.
Economic viability		Return on fixed capital assets. Access to markets	Farm gross margins Farm profit Net household income	Affordability of health, education	Contributions to / claims on social welfare.
Production risk/ security	Pest/ disease risks. Months with lack of water Flood and fire risk Cultivation of 'marginal' land	(Investment in) flood control and irrigation infrastructure.	Output and input price variability; Savings and debt levels Credit access Income diversity Insurance Welfare/pensions	Health status Educational attainment Unemployment	Security of crop, livestock from theft, damage; Security of land use rights Government food security measures; Gifts, loans in times of need
Protection from degradation	Soil 'quality', Soil erosion Pesticide use and toxicity levels Agro- biodiversity Ground cover (deforestation) Conservation technologies				Environmental; organisations, campaigns; Local natural resource management authorities, organisations
Social acceptability	Conflicts over access to, or tenure of, land, water etc	Distribution of access to infrastructure, equipment	Income distribution within society / 'community' / household	Inequality in access to health / education / training	Accountability of elected or customary representation or leadership Social exclusion.

VI. Socio-Ecologicai Indicators for Sustainability

For each of the socio-ecological principles reviewed in the previous section we define a set of socio-ecological indicators. These indicators are formulated so that they reflect to what extent (a certain aspect of) a societal activity violates the corresponding principle.

a) Indicators for Principle[1]

The basic idea behind the first principle is that the total flow of an element from the lithosphere to the ecosphere — i.e., societal emissions of an element extracted from the lithosphere as well as weathering and volcanic processes, should not exceed the return flow of the same element from the ecosphere to the lithosphere, by sedimentation processes and by flows to final deposits in the lithosphere.

As a starting point for the formulation of indicators for Principle 1, we use Fig. 4, which shows some basic features of the cycle of a specific element between the lithosphere, the technosphere and the ecosphere.

The variables used are XT and XEfor the total contents of the element in the technosphere and the ecosphere, respectively, and XR for the total resources. Furthermore, kex is the annual rate of extraction, kw is the total natural contribution to ecosphere (i.e., weathering and volcanic eruptions), kem represents the emissions of the element from the technosphere and ks is the rate of sedimentation from the ecosphere to the lithosphere. It should be observed that in general ksis an increasing function of the total content in the ecosphere. Society can prevent the accumulation of lithospheric materials in the ecosphere by (i) limiting the extraction rate, (ii) limiting the leakage from the technosphere—i.e., by using high degree of recycling and by avoidingdissipative use, (iii) returning the material to underground repositories (dashed line in Fig. 4) and (iv) increasing the sedimentation rate (e.g., by guiding the emissions from the technosphere to areas in the ecosphere where the sedimentation rate is high).

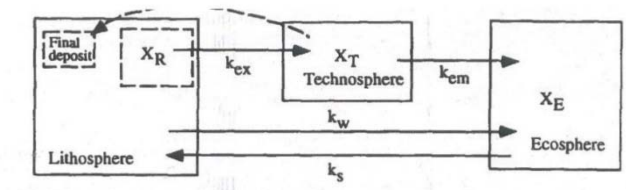

Figure 4 : An element is extracted from the lithosphere and used in the technosphere.

Eventually it will be emitted to the ecosphere. where it will remain until sedimentation processes once again bury it in the lithosphere. The figure shows that the total contents of the element will increase in the ecosphere if the total emissions from the lechnosphere(kem) plus the natural flow from the lithosphere (kw) exceed the rate of sedimentation (ks). The dashed tine represents direct flows from the technosphere to the lithosphere for final deposition in repositories. At present, this option is only planned for radioactive waste.

There are several reasons for putting the focus early in the causal chain when indicating Principle I. The elements that are extracted do not disappear and as long as we do not have clever strategies for preventing accumulation in the ecosphere, a plausible first approximation is therefore that the elements extracted will eventually leak to the ecosphere. Furthermore, the diffuse emissions from the consumption sector of the economy now exceed the more easily detected emissions from the production sector for many elements. Bergback (1992) has shown that this is the case for many metals used in Sweden. The residential time is often longer in the consumption sector than in the production sector.

b) Socio-ecological indicators based on Principle 2

According to the second socio-ecological principle for sustainability, substances that are produced in society must not systematically accumulate in the ecosphere. Here, we formulate socio-ecological indicators for substances that are naturally existingand for substances that are foreign to nature.

i. *Indicators for man-made substances that are naturally existing*

The main idea behind the two first principles for a sustainable society is that sustainability requires that human disruption of the natural cycles and flows of substances are small enough to avoid a systematic accumulation.

Table 3 : Indicators for elements extracted from the lithosphere

Element	Cone, in soils (mg/kg)	Weathering ^{J} and voluanic (kion)	Mining (kum)	Fossil fuels ^{b}(kton)	$I_{1.1}{}^{c}$	$I_{1.2}{}^{d}$
			Metals			
Al	72000	1 100000	18000	34000	0.048	0.01
Fe	26000	390000	540000	34000	1.4	1
K	15000	230000	24000	340	0.11	
Mg	9000	140000	3100	690	0.028	0.01
Ti	2900	44000	2500	1700	0.096	0.02
Mn	550	8300	8600	170	1.1	
Zr	230	3500	880	140	0.3	
V	80	1200	32	350	0.32	
Zn	60	910	7300	260	8.3	6.9
Cr	54	830	3800	34	4.6	2.6
Cu	25	380	9000	55	24	23
U	24	360	9.9	220	0.64	
Ni	19	300	880	570	4.8	2
Pb	19	290	3300	85	12	19
Ga	17	260	0.037	24	0.092	
Nb	11	170	14	14	0.17	
U	2.7	41	47	3.4	1.2	
Sr,	1.3	20	210	5.7	11	
Mo	0.97	15	110	17	8.5	4.2
Be	0.92	14	0.34	10	0.76	
Cd	0.35	5.3	20	3.4	3.9	3
Hg	0.09	1.4	5.2	10	6.5	17
&»	0.05	0.75	15	1.7	22	
			Semi-metals			
Si	310000	4700000	4600	95000	0.021	
B	33	500	0.37	250	0.52	

As	7.2	110	19	18	0.33	
&e	1.2	18	0.27	17	0.96	
Sb	0.66	9.9	54	10	6	
Non-metals						
C	25000	780000		5400000	6.4	
S	1600	33000	58000	100000	3.7	
F	950	14000	2300	240	0.17	
P	430	6500	21000	1700	3.5	
Se	0.39	5.9	2.1	12	2	

[a] Weathering mobilization is calculated using average concentration in soils (column I) und suspended sediment flux of 1.5 • 1016 g per year in rivers (Nriagu, 1990),

[b]Data for contents of trace elements in crude oil are from USA (Yen. 1975). However, the only elements for which flow associated with crude oil are considerable compared with the flow associated with coal are V, Ni and Hg. The flows of elements associated with fossil fuels predominate over the amount that is mined for several elements: e.g., V, Li,Gu, Be. Hg, Si, B. Ge, S, Se and, of course, for C. Surprisingly, thisis also true for aluminium.

[c]Indicator I1.1 is calculated as anthropogenic flows from the lithosphere to the ecosphere divided by the natural flows. The anthropogenic flows are mining and flows associated with fossil fuels and the natural flow-, are weathering and volcanic processes. Data from 1990.

[d] IndicatorI1.2 is calculated as the accumulated mining since 1900 divided by me amount in thetop soil layer in the human area (see the text). If flows from fossil fuels had been included, the indicator value would increase substantially for a number of elements.

Source: BP Statistical Review, Yen (1975). Valkovic (1983).Nriagu (1989), Sposito (1989). Crowsoti (1992), Speight (1992), Wallgren (1992). Walker and Kastings (1992), Sigenthaler and Sarmiemo< 1993), Holmberg el al. (1996) and Karlsson et al. (1994).

Table 4 : Indicators for Principle [2]

Substance	$I_{2.1}$	$I_{2.2}$
CO_2	0.07	1.8[a,b]
CH_4	1.4 - 4.1	2.7 [b]
N_2(g) → N(active)	1.3 – 3	--
N_2O	0.5 – 1	1.5 [b]
NH_3 and NH_4^+	0.02 – 0.09	--
NOx	1.9 -2.6	--
SO_2	0.7 – 6	
C^{14}	0.1	1.1

[a]The value for the second indicator for CO; gives the atmospheric concentration in the year 2100 divided by the pre-industrial concentration, given that the present global emissions are kept constant. In order to estimate the long-term atmospheric concentration of CO2, one has to make assumptions about emissions scenarios and fossil fuels reserves. Maier-Reimer and Hasselman (1987) estimate that for a stock of fossil fuels equal to 5000 Gton C, the atmospheric concentration of CO2 would reach peak concentration as high as 4.5-6.4 times the pre-industrial level (all depending on the rate at which the stock of fossil fuels is combusted). No net-sink in biomass is assumed.

[b] Values from IPCC(I995).

Sources: Bolin (1979). Soderlund and Rosswall (1982), IPCC (1990), IPCC (1992). IPCC (1995), Jaffe (1992), Bates et al. (1992), Graedel and Crutzen (1993), UNSCEAR (1993).

Indicators for Principle [3]

The global population is expected to nearly double by the year 2050 (United Nations. 1992b). In order to provide a sustainable supply of biomass for food, material and energy for the growing population, we need to maintain the services of the ecosystems. These services include, for example, generation and maintenance ofsoils, disposal of wastes and cycling of nutrients, pest control and pollination (Ehrlich and Ehrlich, 1992). This means that the productivity of lands and the biodiversity of ecosystems must not worsen. This is the essence of Principle [3].

Human activities threaten ecosystem productivity and biodiversity in two ways. The exchange of substances between society and nature is dealt with by the indicators for Principles 1 and 2. In this section we focus on societal activities that by manipulation or harvesting of ecosystems may threaten sustainability and, in particular, biodiversity and ecosystem productivity.

ii. *Large-scale transformation of lands*

Since the beginning of the 18th century, humanity has carried out a large scale transformation of the Earth's ecosystems and productive surfaces (see Fig. 3). The area used for crops and grass lands has increased dramatically at the expense of huge losses of primary forests. In the long run this trend is obviously not

c) Indicators for Principle 4

Principles 1, 2 and 3 constitute the framework for a sustainable influence on nature. Principle 4 states that if we want a prosperous society within this framework, the societal metabolism must be efficient and just. This principle covers four aspects: overall efficiency, inter- and intragenerationalequity, and basic human needs. Below, indicators for some of these aspects are given:

i. *Indicator no.4.1: overall efficiency*

A simple schematic description of the societal metabolism is given in Fig. 4. The overall efficiency indicators are measures of the productivity in the technosphere. They indicate how much service13 that is delivered for a certain amount of resources extracted from nature, normalized with respect to the situation a certain year y:

$$\boldsymbol{I_{4.1}} = \frac{\frac{\text{Service}}{E}}{\frac{Service_y}{E_y}}$$

It is also possible to complement the overall efficiency indicators with specific efficiency indicators that focus on the internal conversion in the technosphere— e.g., the flow P per unit of total input E + R, or the recirculation R compared to the total input E + R.

$$\eta_1 = \frac{P}{E+R}; \eta_2 = \frac{R}{E+R};$$

The recirculation flow R can also be compared to the total output $P^* + L$:

$$\eta_3 = \frac{R}{P^* + L}$$

In a stationary state P equals P^* and E equals D. It is possible to normalize the efficiencies with normalization values η_n determined according to various principles: a normalization to the maximum possible theoretical value, to the best available technology (BAT), or to a desirable value. We get complementary efficiency indicators:

$$I_i = \frac{\eta_i}{\eta_n},$$

where i = 1, 2, 3. In Table 7 some examples of overall efficiency indicators are shown. We can see, for instance, that the supply of food per hectare of land has increased, whereas the supply of food per phosphate input has decreased since 1970.

Table 5 : Overall efficiency indicators

Efficiency indicators	1970	1980	(1987) 1990
Food			
Calories in food/Phosphate input (World)	1	0.67	(0.61)
Proteins in food/Phosphate input (World)	1	0.66	(0.60)
Fats in food/Phosphate input (World)	1	0.69	(0.67)
Calories in food/ Area input (World)	1	1.03	(1.08)
Proteins in food/ Area input (World)	1	1.01	(1.07)
Fats in food/Area input (World) '	1	1.07	(1.18)
Energy			
GDP/Primary energy input to the World (USD/J)	1	1.07	1.21
GDP/Primary energy input to Sweden (USD/J)	1	1.06	1.12
Dwelling area/Primary energy input to the dwelling sector in Sweden (m^2/J)	1	1.11	1.14
Personal transport/Primary energy input to personal transport in Sweden (Pers. km/J)	1	0.91	0.99
Goods transport/Primary energy input to goods transport in Sweden (ton km/J)	1	1.06	0.93

The values are normalized to the year 1970.

Sources: Bumb (1989), FAO Food Balance Sheet (FAO. 1991). Schipper et al. (1994) and Brown ei al. (1994).

As an example of a complementary specific efficiency indicator we have chosen to indicate the efficiency of the use of nutrients in the Swedish agricultural system. This indicator is defined as;

$$\eta = \frac{\text{Nutrients in provisions from the Swedish agricultural system}}{\text{The supply of nutrients to the Swedish agricultural system}}$$

VII. Epilogue

This paper has set out an analytical framework based on the Sustainable Rural Livelihoods approach, and used this to generate a matrix of potential indicators compatible with five 'dimensions of sustainability' from commonly-used indicator frameworks. In doing this we have sought to bring together disparate components of the 'sustainability' literature into a single methodological approach. In setting out to test the applicability of this approach in assessing the sustainability of farming in East and Southern Africa, we recognise that exclusive reliance on a predetermined set of indicators to be measured at each case study site would be a mistake. Firstly, indicators may vary in their relevance according to the local environment and the final purpose of their measurement and monitoring (and the practicality of this measurement). Secondly, it is important to test externally-defined indicators against local stakeholders' criteria for valid indicators of the success and sustainability of their agricultural systems and livelihoods.

The main emphasis of this paper is the method for developing socio-ecological indicators for sustainability. Such indicators should be (i) based on a framework for sustainability (the four socio-ecological principles for sustainability) and (ii) focus early in the causal chain.

Practical experience from companies and local authorities has shown that the socio-ecological principles that we have used as a systematic framework, function well when making strategic decisions.

There are no exact limits defining sustainability. Instead, the border between sustainability and unsustainability is not sharp. This means that it is not possible to determine exact reference values for sustainability. However, many of the societal activities today are far from sustainable, which means that time series of the indicators would enable us to say whether sustainability is approached or not. However, it would also be a mistake if no "external" framework or set of indicators were to be identified based on prior knowledge and technical expertise. This is important to ensure a basis of comparison between different study sites, to assess the robustness of the methodological approach proposed, and to permit valid policy conclusions. For this, success or sustainability of an agricultural system needs to be assessed from different perspectives: local or farmers' perspectives as well as the scientific or technical. It is therefore useful to start off with a core set of indicators around which a final set will be built using stakeholders' indicators. It follows logically from this that the methodology of identifying indicators will be important. This should deliver:

- locally relevant and easily measurable indicators;
- indicators which represent the potential diversity of perspectives of different users on success and sustainability- from farmers/local communities (both wealthy and poor), through scientists, to policy makers;
- indicators which encompass both agricultural systems and peoples' livelihoods;
- indicators which can be "related" to policy; and,
- the smallest number of indicators possible, to make any assessment of success or sustainability of agricultural systems and livelihoods relevant.

The research steps set out above are, obviously, presented sequentially. The process in reality should be characterised by loops and feedback between the various people involved (most importantly, the various project teams and the inhabitants of the study areas).

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