CHAPTER 6

On Designing Socio-Ecological Indicators

by

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There is a need for indicators which capture the essential parts of society in the maladjustments of its physical relations to nature. The socio-ecological indicators should contribute to the control mechanisms that are urgently needed if society is to be able to redirect itself to a path of development which is subordinated to sustainable interactions with nature. An analysis of various factors important to the design of socio-ecological indicators is performed here. An important aspect of the socio-ecological indicators is that they will focus on parts situated early in the cause-effect chain. This implies better possibilities for foresights when dealing with the global, complex or diffuse problems in connection to sustainability. The indicators can be useful in many situations: as a support for discussions among decision-makers and the general public, as part of an environmental impact analysis, and as a tool in the evaluation of various plans or projects.

1. INTRODUCTION

The picture of the environmental problems has changed. From local disturbances a few decades ago, environmental problems have changed and several of them now have a global character: the greenhouse effect, the destruction of the ozone layer, and the disturbances of the biogeochemical cycles. The traditional 'large-chimney-

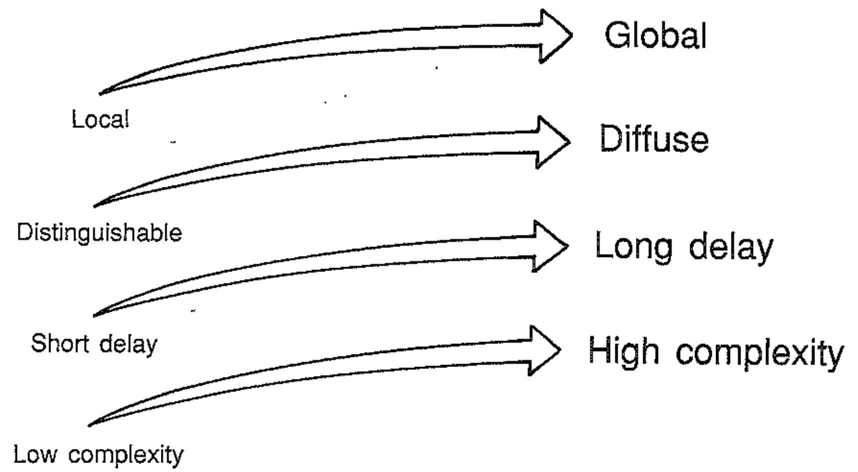

Figure 1. The changing character of the environmental problems.

emitting-smoke' picture of the TV news is no longer a relevant illustration of environmental problems. Many pollution problems no longer originate from big distinguishable pollutant sources but from many small diffuse discharges. The problems are shifting from the production processes to the contents of the products themselves, as well as deposits of emission reduction devices. This change in the character of the problems implies that the time from the original activity to the damage in many cases has increased. Dangerous substances embedded in the products are stored and delayed in society before they are dispersed in nature. The primary sectors, such as agriculture and forestry, are the major sources of several diffuse pollutants due to the management practices over large areas. Many problems are also very complex in that many sectors of society contribute to the problems in various ways. Figure 1 illustrates the above-mentioned aspects of environmental problems.

The change of the environmental problems has led to an emerging awareness that the physical relation between society and nature is no longer sustainable. Further degradation of nature will follow, unless this relation is changed (World Commission on Environment and Development, 1987).

Societal control mechanisms which used to function well, are no longer reliable. The change of the environmental problems has made it impossible to detect the problems directly with our senses, but we still need to have mechanisms that make us aware of our influence on nature.

2. THE NEED FOR SOCIO-ECOLOGICAL INDICATORS

Socio-ecological indicators are intended as a tool for structuring the problems and stressing the essential parts of our influence on nature. The indicators should especially focus on factors of crucial importance for maintaining a sustainable relation to nature. Another desirable quality is that they should give an early warning signal, by operating as early as possible in the cause-effect chain. Hopefully they can then contribute to an enlightened discussion among decision-makers, as well as among the general public, to environmental impact analysis of various projects, and to the formulation of local or regional environmental goals.

Environmental care has generally developed from a registration of symptoms, over curing, to a more preventive view. This may be a general tendency within activities constituting a burden for society. There is a long-term tendency of increasing the backing up of health care as a complement to hospital treatment. But whereas health care contains strong internalizing components, since people do not want to be sick, and the problem is rather lack of knowledge or insufficient foresight, many environmental problems which give rise to non-sustainability contain few apparent feedbacks to the agents. This is a good reason for making externalities known, even if they cannot be directly internalized within socio-economic evaluations. Socio-ecological indicators can serve a purpose here.

The problems with knowledge and foresight become more important when the effects are external. Socio-ecological indicators aim at *information* and *foresight*. This is what distinguishes them from environmental indicators, which concentrate on the *symptoms* or the *problems*. The Council on Environmental Quality in the USA has defined an environmental indicator as an environmental parameter, a theoretical concept, or an aggregation of data that provides a surrogate representation of some aspects of environmental quality or condition. The socio-ecological indicators are directed towards *societal causes* or their possible or potential solutions. They are directed towards agents and their practices in society. This is especially important when dealing with pollution, which is eventually deposited after being transported over long distances. For example, in south-western Sweden the contribution from domestic sources to the deposition of nitrogen oxides is relatively small; the major part of the deposition comes from abroad.

Similarly, pollution discharged within the area of interest is transported to other areas and countries. Socio-ecological indicators may therefore be connected to the effects of the discharge from domestic sources as well as to the influences of the deposition originating from external sources. Socio-ecological indicators can be formulated to include a correction considering the export/import.

The environmental problems often act as externalities in the economy of society. These social costs are often not included in the considerations of the agents. One way of handling the environmental externalities may be to internalize them by including them in economical considerations. However, the costs of many environmental disturbances are hard to identify and evaluate. In such cases the indicators can clarify the necessary adjustments without relying on a specification of the external costs. The indicators can provide the starting point for a determination of standards or charges.

2.1 When are Socio-ecological Indicators Especially Suitable?

Examples of situations for which socio-ecological indicators are especially important, or form a complement to other types of information, may be:

– *Problems of global or international character*

1. When the disturbances cannot be assigned to a specific country or activity. For instance, when a pollutant from any local source is dispersed in the same distribution pattern across the globe, which holds for greenhouse gases and gases which destroy the ozone layer.
2. When the pollutants are imported and/or exported across national borders, e.g., SO_2 and NO_x transported by winds and pollutants transported by rivers and streams.

– *Problems from diffuse pollution sources*

3. When there are many diffuse sources of pollution instead of a few distinguishable ones. The emission of cadmium from point sources (e.g., factories) has been strongly reduced while the emission from products increases.

– *Problems with long delay*

4. When the foresight has to be extensive. An example is non-linear problems, i.e., when we expect the effect of an additional disturbance to rise dramatically in the future.
5. When there is a long time interval between the original social activity and the eventual environmental disturbance. The greatest amount of the mined cadmium and chromium is still embedded in products and will eventually leak out when they are used or wasted.
6. When environmental protection requires long-term protective handling in the future. This is the case for certain types of radioactive wastes.

– *Problems with high complexity*

7. When both societal and natural processes are contributing to a disturbance, e.g., the fixation of nitrogen through fertilizer manufacturing and through biological fixation.
8. When different societal sectors contribute to the disturbance, e.g., nitrogen fixation within food production and within communication/transportation.
9. When there are environmentally important joint products, e.g., heavy metals and acidifying substances emitted from the transport sector.
10. When various agents contribute very differently to a problem depending on methods, behaviour, lifestyle, etc. Various recreational activities have, e.g., very different implications for the environment.

How should one design such indicators? Before going into this, we shall discuss some basics of the physical relations between society and the environment.

3. SOCIETY AND NATURE

The earth is embedded in a flow of *energy* between the hot sun and cold space. It receives short-wave electromagnetic radiation from the sun. This radiation can be approximated with black body radiation with a temperature of around 5,800 K. An equal amount of long-wave radiation is emitted from earth into space. Space may here be treated as a black body with a temperature of 2.7 K. The *entropy* content in black body radiation is proportional to the inverse temperature. The received short-wave radiation therefore has a low entropy content, while the entropy flow in the outgoing radiation is much larger. There is, thus, a net outflow of entropy from the earth.

In other words, earth receives a flow of *exergy* (ordered energy, available work) from the hot sun and cold space (Karlsson, 1990). The exergy supplied is capable of maintaining flows of energy and materials on earth and to create various structures. The exergy can maintain the structures away from thermodynamic equilibrium (which implies an entropy content lower than that for the corresponding equilibrium). These structures have been called dissipative structures or self-organizing systems. When discussing the relation between society and nature, it is advisable to distinguish that part of the earth which maintains its structures and flows through the conversion of the exergy delivered in the exchange of energy between earth and the sun/space. In this text we will call this part of earth the *ecosphere*.

With this definition the ecosphere contains the biosphere, the atmosphere, the hydrosphere, the uppermost part of solid earth, i.e., the pedosphere. The rest of earth/nature we will call the *lithosphere*. Processes in the lithosphere are mainly driven by radioactive decays within solid earth.

Nature is mainly characterized by linear flows of energy and circular flows of materials. The various energy flows in the ecosphere consist of energy on its way from sun to space. There is also a small flow of energy and exergy from gravity and rotation within the solar system giving rise to tidal phenomena. The lithospheric radioactive decays start a one-way flow of energy from within the atomic nuclei inside the earth. Eventually the flow ends up in space. However, this flow is much smaller than the energy throughflow in the ecosphere.

The total mass of the materials as well as the total mass of single elements on the earth is conserved. (We can here disregard the small deviations from mass conservation due to radioactive decays and certain exchange of materials with space.) The radiation exergy inflow maintains a circulation of the elements in biogeochemical cycles within the ecosphere. On longer time scales, these cycles are significantly influenced by interaction with lithospheric geological processes. There is a slow exchange of materials (and energy) between the litosphere and the ecosphere, e.g., inflows to the ecosphere through volcanos and weathering and outflows through various sedimentation processes.

New minerals are also continuously created and concentrated in the litosphere. But these processes are of importance only in a longer time perspective, and therefore from the societal point of view, these resources are treated as given and finite.

Society uses structures, flows and functions in nature to build, operate, maintain and change the material side of society, i.e., the *technosphere*. This part forms/brings about a large part of society's influence on the ecosphere. With the present functioning of the technosphere, ecospherical flows, such as the biogeochemical cycles, and the ecospherical structures, such as various habitats and life forms, are disturbed. Humankind's extraction of fossil fuels and mining activities also involve a continued delivery of geological and lithospherical materials to the ecosphere, where they are to a large extent accumulated.

Society also has another side, here called the *human sphere*. The technosphere is used as a means to deliver services to the human sphere, which performs the ultimate control of the technosphere. The services are delivered in various final-use processes, which normally also imply a conversion of energy and materials. Even if we dispose materials over certain time periods, we only consume the qualitative aspects, e.g., the exergy or the structure, of energy and materials. Energy and materials are degraded, but nothing disappears (Ayres, 1978).

4. THE PHYSICAL RELATION BETWEEN SOCIETY AND NATURE

We can discern two main mechanisms for the physical influence of society on nature. Activities in society will imply in various proportions a mixture of
– exchange, i.e., influence through flows of energy and material between nature and society;
– manipulation, i.e., influence by displacement or control of subsystems of the ecosphere.

These mechanisms are illustrated in Figure 2. The *exchange* takes place in the form of flows of energy and materials. The outflow from nature to society consists of, for example, materials resources (useful to society). The inflow back into nature may consist of discharges of molecular and energy refuse or waste disposal from society.

The *outflow* of energy and materials from the ecosphere and the lithosphere into society is based on structure-creating processes in nature. These processes create, or have created in the past, various resources as natural flow resources, deposits and funds. The natural flow resources are continuously flowing resources (sunlight, winds, ocean currents, etc.), from which society can deflect a flow. The funds (forests, fish populations, etc.) are maintained by natural flows. When parts of the funds are harvested they decrease temporarily, but will regrow as long as they are not irreversibly damaged. The deposits (oils, minerals, metals, etc.) have no or very limited regrowth possibility within the relevant time horizon and are therefore gradually depleted when extracted.

The ecosphere has a limited assimilation capacity for the *inflow* of energy and materials back from society. The assimilation processes rely on functions like transportation, transformation, dilution, etc. The in- and outflows are linked via conservation laws for energy and materials. The material in a fund resource may be circulated through incorporation in the biogeochemical cycles. When we use deposit resources, material is transported from the earth's crust into the technosphere, but

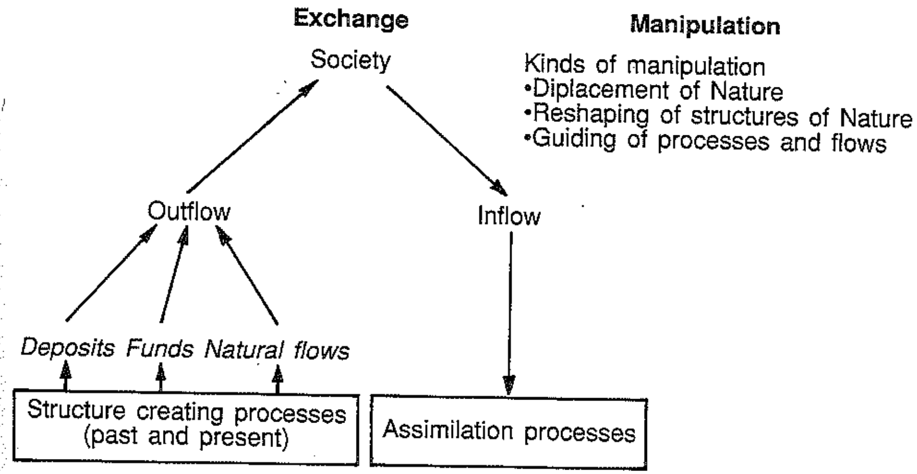

Figure 2. General mechanisms for the physical influence of society on nature.

we also need a recipient for processing the used material, the waste. The normal recipient, the ecosphere and life in the ecosphere, is often badly adapted to increasing concentrations of many materials which have earlier been stored in the earth's crust. This holds for the substances (e.g., strange materials) created in the extensive transformations of materials and structures taking place in the technosphere.

Society also influences the ecosphere via *manipulation*, which can imply:
– a *displacement* of the ecosphere (the artefacts and societal activities of the technosphere force away or disturb ecological systems or geophysical functions, e.g., by the hardening of surfaces);
– a *reshaping* of the structures of the ecosphere (e.g., damming of rivers, ditching, ploughing); and
– a *guiding* of processes and flows (e.g., agricultural practices, manipulation of genes).

We have different degrees of manipulated areas from cities and roads, hydropower dams, agricultural areas and highly manipulated forests, to oceans and remote mountain areas. In fact nearly 40 per cent of potential terrestrial net primary production is used directly, co-opted, or foregone because of human activities (Vitousek *et al.*, 1986).

5. WHAT DOES SUSTAINABILITY INVOLVE?

Sustainability of the society-nature relation may refer to the maintenance of natural systems, which can be motivated by the need for society to maintain over time the fundamental prerequisites given by the natural systems, the *instrumental values*. It may also be argued that there are *intrinsic values* of the ecosphere as well as the lithosphere. Natural systems will, when left alone, maintain and develop themselves (in their own way). Maintenance of natural systems therefore mostly concerns a defence against humankind's destruction of the ecosphere in their efforts to use nature to maintain and develop their societal systems. This conflict is implicit in the Brundtland Commission's concept of sustainable development. Often development refers to the societal systems and sustainability to the natural systems.

Humankind has already strongly intervened in the natural systems. A large fraction of nature is not natural in the sense that it is not that type of nature that would exist without man. A conservation of this historical situation will evidently imply a continued intervention. The present relation to the ecosphere is in several aspects not sustainable in the long run. A purely conservative claim may therefore not be functional. That is, while conserving certain aspects of our relation to nature we urgently need changes in others.

The efforts must first of all be directed towards these parts of the structures, flows and functions within the ecosphere which are irreplaceable or hard to replace. More specifically, the claims may be directed towards a maintenance (non-degradation) of

1) the functioning of the ecosphere, its productivity and stability, especially concerning the conditions that are important for humankind (e.g., protection against excess of ultraviolet radiation, stability of climate and other prerequisites for biological production);
2) biological diversity (i.e., maintenance of genetic material with possibilities of genetic development, vital populations of species).

Exhaustible resources from the lithosphere concentrated during the geological history are natural conditions transferred over generations. Maintenance may therefore include

3) a restriction on the extraction of non-renewable resources.

Maintenance places demands on the relation between nature and society. We have to translate those demands into specific restrictions on the exchange with and manipulation of nature. This indirectly implies restrictions on the internal conversion of energy and materials in the technosphere. We thus have three different types of generic relations:
– the exchange between society and nature;
– the internal conversions in society; and
– society's manipulation of nature.

6. THE DESIGN OF SOCIO-ECOLOGICAL INDICATORS

Generally indicators need to be nothing more than that: indicators. *Exact measures are not necessary*. We can compare this with the current use of the concept of GNP (Gross National Product). GNP is only an indirect measure of prosperity or welfare production, not a direct one. But on the other hand, there is inevitably a connection between increasing GNP and an increase of prosperity, so we cannot claim GNP to be irrelevant for the measurement of prosperity. This is important when moving the focus away from measurements of effects on nature towards the internal flows within society. This will be done at the price of a certain loss of accuracy in the connection to the environmental problems.

6.1 Socio-ecological Indicators for the Exchange

Socio-ecological indicators can be given various designs and it is desirable to normalize the indicators in such a way that they are dimensionless. Socio-ecological indicators for an exchange may give a measure of society's *maladjustment* in its exchange with nature. For example, they can show the load of society on nature in relation to an acceptable level. This means that indicators get an increasing value with increasing disturbances. An alternative formulation is to indicate society's *adjustment*, i.e., how well society is adapted to nature. Maladjustment is then indicated with a low value. However, the latter alternative can be misinterpreted if we are used to values being too high when there is an error (compare various pollutants). We can give a general layout for the former type of indicator I_x according to

$$I_x = \frac{A/B}{C/D}$$

where A is the quantity to be indicated; B is the size of the compartment for which the measure of A holds; and C/D is a relevant normalization of A/B, expressed in the same unit, which implies that I_x is dimensionless.

What Should Be Indicated?

The quantity A can be the present exchange measured in a physical unit such as mass flow per unit of time, e.g., flow of carbon dioxide in megatons per year. Here we are facing the main problem discussed in the previous section. But what is a relevant exchange to be indicated? This discussion can have as its starting point that the different indicators must relate to the various potential problems, i.e., the threats against sustainability, and to the addressees, i.e., the social agents. The indicators can be formulated around different steps in the chain from agents via activities and discharge substances, to a change of the state of nature, as shown in Figure 3.

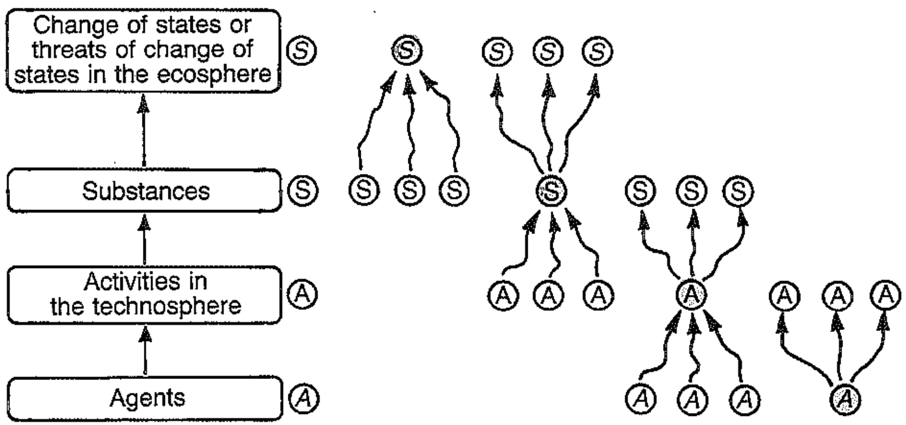

Figure 3. Various types of connections in the cause-effect chains for exchanges.

Following the chain back towards the agent we will find that flows of several different substances can give rise to the same threat. Each substance can emanate from different activities as well as different agents. For instance, we have a number of different greenhouse gases and each greenhouse gas comes from a number of different societal activities serving various purposes. We also have the reversed relation: a number of environmental threats can be related to one and the same flow, to one and the same activity or to one and the same agent. For example, traffic generates many emissions, e.g., various nitrogen oxides that contribute to the acidification of soils, to the depletion of the stratospheric ozone layer, and to the accumulation of greenhouse gases in the atmosphere.

In this web of agents/activities/substances/threats, indicators can be designed from different perspectives. They can, for instance, indicate the contributions to various *threats* of possible changes in the state of nature. Persson (1990) has suggested the following 12 conclusive threats: changes of climate, diminished stratospheric ozone layer, acidification, increased proportions of tropospheric ozone, eutrophication, increased proportions of metals, presence of environmentally hazardous organic compounds, effects on health, changes of landscape (scenery), diminishing biological diversity, the introduction of new and strange organisms, and over-exploitation of natural resources. For instance, an indicator for the changes of climate may then add the weighted effects of a number of greenhouse gases, indicate the collective contribution from traffic to the greenhouse gases or the contribution to the greenhouse effect of an individual due to his consumption and lifestyle. The concept of 'global warming potential' may be useful in this context. This shows the integrated radiative forcing effect per kilogram from various greenhouse gases compared to that from carbon dioxide (Houghton *et al.*, 1990).

Indicators can also be related to different chemical *substances* or groups of

substances which society exchanges with nature, but which can contribute to different threats. This type of indication can be used for the heavy metals. In these cases it may be relevant to indicate the intake into society of these substances. There is an increasing storage of most heavy metals in the technosphere. The heavy metal load on the environment is related to the input into the technosphere/the *extraction* from nature, which therefore can be a relevant indication for sustainable exchange. However, in the case of organic compounds produced within the technosphere the delivery to nature may be the only convenient exchange to indicate.

Indicators for Which Compartment?

What is a relevant compartment to focus on depends on which phenomena in the human sphere we want to stress. Compartment B can be society as a whole, where society is a delimited *geographical* region (e.g., a drainage area) or an *administrative region* (e.g., a municipality). A geographic region is often the relevant *problem-oriented* delimitation. The total deposition of a substance to a drainage area may give a good estimate of the potential load to water resources. An administrative region is often the relevant *solution-oriented* area when preventive actions in the form of political decisions are discussed.

Indicators can also be linked to various *agents* in society (*agent-oriented* indicators). We get different agents depending on how we prefer to describe society. One model is that society consists of delimited administrative regions like municipalities, states, etc.; another one is that society consists of producers and consumers. It is also of interest that each consumer is aware of his/her share in the maladjustment due to his/her consumption.

Indicators can be assigned to the total consumption of households or the total production of producers in an administrative region. This means moving away a step from the agent-oriented view. When we leave the single agent and look at aggregates such as the total consumption or the total production, we take on a more *activity-oriented* perspective. The point is similar to that on the individual level. In a small economy it is important that an indicator relates the export/import not only to those who happen to have the production facilities in their vicinity but also to those who demand the products. On the other hand, the administrative regions are to a certain extent responsible for the activity and are perhaps also the ones that can resolve the maladjustment problem, e.g., by changing laws and directions or their own handling of disposals.

We have pointed at the three types of agents: consumers, producers and politicians/administration. Various arguments can stress the responsibility of each of them. Swedish legislation has transferred an increasing part of the responsibility to the municipality. In various countries the principle of producer responsibility for recycling/reuse is now being discussed. Often we are told that the consumer has the power/responsibility to choose.

Many people belong to both categories, that of producers and that of consumers. We can get 'double-entry bookkeeping' if indicators are assigned to both production and consumption. This is not necessarily bad.

Normalization of the Indicators

C/D is a normalization of A/B. The quota are normally expressed in the same unit, which involves that I_x is dimensionless. The indicator can refer to the *influence* on nature by a normalization to the expected *damage* or *risk* created by the exchange. This includes, for instance, a normalization to the critical load of a specific exchange, which may be expressed as an upper limit on the flow in tons per year per unit area. The critical load may be determined by the capacity to assimilate the exchange without being unacceptably disturbed. This can imply that a deposition of material may not lead to an unacceptable accumulation of the material (or the material from successive processes) anywhere in the ecosphere.

When definite values for critical loads are lacking, the normalization may be done by comparing the anthropogenic flows with corresponding *natural flows*. This means that the indicator will constitute a human *disruption* index (Holdren, 1990). Holdren estimated this index for the global flows of lead, cadmium and mercury to 15, 8, and 0.7 respectively.

The indication can also be given a positive form by a normalization to the *possible/potential flows*, and in this way demonstrate the practical or theoretical possibilities to reduce the harmfulness or to enhance the resource extraction. This gives indicators corresponding to different measures of *efficiency*. In these cases the relation to the harmfulness is only of an indirect character.

Depending on the problem faced we can have various relevant compartments D. For genuinely global problems the only relevant D compartment is the earth itself, possibly modified by a scaling factor. An example of this type of problem is when a pollutant is dispersed according to the same distribution pattern across the globe independent of where it is emitted. This holds for instance for carbon dioxide and other greenhouse gases, for which the characteristic mixing time in the atmosphere is much smaller than the effective turnover time and therefore the gases are dispersed in equal concentrations in the global troposphere.

6.2 Socio-ecological Indicators for the Internal Conversion

When discussing socio-ecological indicators for internal conversion within the technosphere, we can start from the limitations on the exchange. Normally a sustainable exchange should not exceed certain levels of in- and outflow. A specific technosphere with the corresponding flows of materials and energy is able to deliver a certain flow of services. To increase the service flow without increasing the exchange, the efficiency of the internal physical flows must increase, i.e., more service must be delivered for each unit of exchange. The physical flows can, for instance, be energy, exergy, different kinds of materials or products. A simple schematic description of the situation is given in Figure 4.

There are several ways to obtain more service for the same exchange. The efficiency may be increased by raising the productivity p, i.e., more service per unit of physical flow P in the service production of the consumption process

$$p = \frac{\text{service}}{P}$$

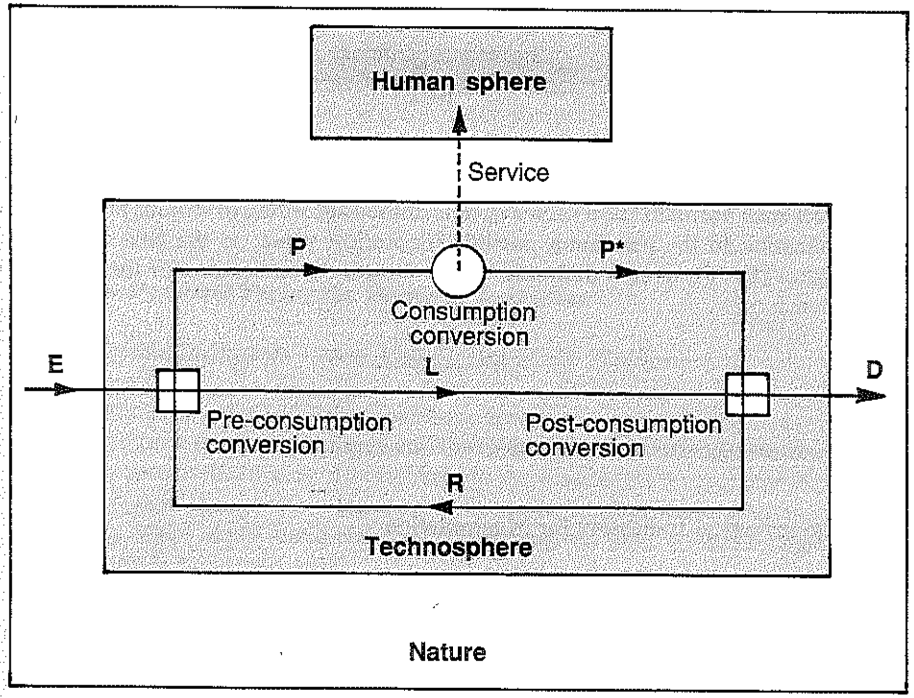

Figure 4. A schematic illustration of the physical flows within the technosphere. Substances E extracted from nature and internally recirculated substances R are converted into products P and losses L within the pre-consumption conversion. (Some of the substances [e.g., the elements] may be turned into products without conversion.) P delivers services to the human sphere when used in the consumption conversion. After the consumption, used products P together with L are possibly converted, and thereafter sent into the recirculated fraction R or are deposited in the ecosphere D.*

by increasing the flow P per unit of total input E+R, or by increasing the share of recirculation R compared to the total input E+R. For conserved quantities the corresponding efficiencies are

$$\eta = \frac{P}{E+R}$$

$$\eta = \frac{R}{E+R}$$

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

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

In a stationary state P equals P*, while 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 technologies (BAT), or to a desirable value. We get the indicators for the internal conversion I_i

$$I_i = \frac{\eta}{\eta_n}$$

6.3 Socio-ecological Indicators for Manipulation

Manipulation can cause important effects in nature immediately and/or indirectly through causing flows of substances (Figure 5). For instance, agricultural practices can lead to unacceptable flows of methane or dinitrogen oxide, two greenhouse gases. On the other hand, exchange can have effects similar to effects caused by manipulation. Erosion caused by emissions of acid substances is one example. This implies that the border line between exchange and manipulation is not always sharp.

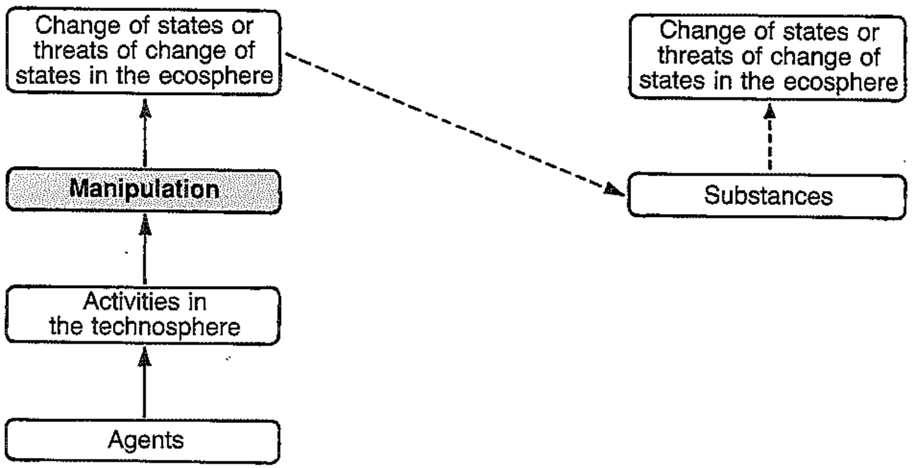

Figure 5. A schematic picture of the cause-effect chain for manipulation.

In cases when manipulation leads to important flows of substances, the indicators do not need to differ from the exchange indicators.

However, there are immediate effects of manipulation, which do not have the same character as exchange. We can refer to some of these effects as different degrees of manipulation of ecological systems. When indicators are designed for this kind of manipulation, the disruption can be normalized to the tolerable disruption level as in the exchange case.

6.4 Some Problems Facing the Design of Indicators

Clarity of the Indicators Versus Complexity of the Problems

Socio-ecological indicators for an exchange tend to be simple: they can, for instance, consist of a ratio between discharge and the tolerance level of nature. However, there is a policy gain in the linking of a discharge to the sustainable level or, for example, in making evident the contributions from individuals. Furthermore, when information is lacking, it can imply that a claim is laid to bring out the information and that the information is presented at all.

More complicated socio-ecological indicators can, of course, have the consequences that they do not add much relevant information but are just complicated. To a certain extent this is coherent with the character of the environmental problems as *technical fix problems* in the components or as *system failures*. If there are system failures it is plausible that seemingly complicated indicators can give a measure of these failures. By more complicated indicators we do not necessarily mean complicated to evaluate. One example could be the fixation of nitrogen as a measure of the environmental disturbances in the cycle of nitrogen, disturbances giving rise to a number of different environmental effects. If, on the other hand, the problem is simply 'too big discharges', complicated indicators can confuse more than they inform about problems, unless there is a common disturbance for several emissions, as in the case of, e.g., greenhouse gases.

Non-linearity Problems

Environmental problems often have a *non-linear* character; e.g., nature has a limited buffering capacity against acid precipitation. Furthermore, the tolerance in society against environmental disturbances may be decreasing for increasing disturbances. This is illustrated by the idea of critical loads. Disposals may be unacceptable above a certain level of effects but relatively acceptable below this level, even if nature is somewhat affected in this case. (However, there may also be an adaptation to environmental problems, especially if references to undisturbed nature, accessible or well documented, are lost.)

The non-linearity leads to the fact that a certain contribution to an environmental disturbance is acceptable only if there is no risk of a collective effect due to a lot of other contributions. The contribution of an individual will then be interesting as a marginal disturbance. The only thing that is important, therefore, seen strictly from the *point of view of the disturbance*, is what everyone together is doing, while the personal behaviour can be as relevant seen from the *point of view of the policy*. Indicating a specific agent in these non-linear cases must be motivated from the point of view of policy. Socio-ecological indicators are therefore closer to the point of view of policy than to the point of view of disturbance.

The Problem of Normalizing the Share of the Contribution to a Subsequent Link

It is in principle possible to accomplish any partitioning of the contribution to a common effect in a subsequent link of a cause-effect chain, e.g., a distribution of an environmental threat over different substances, activities or individuals in accordance with their marginal contribution. However, if an indicator is to correspond to a normalized part there must be a principle for dealing with the normalization. For non-homogeneous categories like different activities or chemical compounds, there is no easily accepted principle of normalization. How big a share of the greenhouse effect is an acceptable share for different gases? How big a share of the threat is a reasonable share for the traffic? On an individual level it may be easier, as one can argue that this group is homogeneous (the equality of all individuals).

How to normalize such an indicator is another question. The example with carbon dioxide emissions is illuminating. A simple scaling mechanism can be motivated only from the notion that it is important to bring the disturbance down to individual agents. The indicators are then a hint of the relative level for various individuals. But is the individual in Sweden or Sweden as a whole responsible for the discharge? The individual contribution often follows the consumption which depends on income, related to the income distribution. A high relative income may be accepted by society for various reasons, for instance, reasons of efficiency. One possibility is therefore to indicate the carbon dioxide emission per unit of consumption. (*If* translated to the level of countries, which may not at all be acceptable, this would mean that poor countries have no right to large emissions of carbon dioxide relative to income, simply because of their low per-capita income.) However, in a society with large interdependences between the individuals, other principles for a just distribution, for example, involving parameters related to countryside/cities or type of work, may be needed to get an acceptance for a normalization.

Different countries and different agents also have different prerequisites to contribute to the reduction of carbon dioxide. Evidently, countries with large available quantities of renewable flows per capita in the form of hydropower, net photosynthesis, etc., have better possibilities to keep the carbon dioxide emissions at a low level. An indicator not considering these differences can be less well-designed seen from the point of view of policy. We can here compare with the concept of marketable pollution permits (or generally exchange permits). The idea of those permits is that the separate agents make the same marginal sacrifices. An acceptance of marketable pollution permits at the international level therefore means support for the above reasoning. Poor countries cannot afford large emissions. How the permits of exchange should *initially* be distributed is another question and could lead to an

initial transfer of money. Another problem associated with the problem of distribution across agents is the distribution in time, a problem which will not be discussed here.

For a distribution across individual companies, it is impossible in other than exceptional cases to motivate agent-normalized indicators. Normalized values have been proposed for energy use in Swedish buildings. These values take the form of calculated *desirable* levels, expressed as energy use per sq. m for specific types of buildings. This normalization gives indicators, which can be characterized as *physically-oriented indicators*.

The Summing-up Problem of Calculating the Assembled Effect in Subsequent Links

We can face a similar but reversed problem if we are interested in indicating the total contribution to different environmental effects from one agent or one substance, etc. An indication of the total effects leads to the question how components in the subsequent links should be summarized. For instance, how do we add the various environmental threats (increase of greenhouse gases, eutrophication, acidification, etc.) coming up as consequences of emissions of nitrogen oxides?

7. CONCLUSIONS

The discussion has shown that there is a need for indicators which capture the essential parts of society in the maladjustment of its physical relations to nature. These socio-ecological indicators should contribute to the control mechanisms that are urgently needed if society is to be able to redirect itself to a path of development which is subordinated to sustainable interactions with nature.

An important aspect of socio-ecological indicators is that they will focus on parts situated early in the cause-effect chain. This implies better possibilities for foresights when dealing with global, complex, or diffuse problems in connection to sustainablility.

The indicator can be useful in many situations: as support for discussions among decision-makers and the general public, as part of environmental impact analysis, and as a tool in the evaluation of various plans or projects, etc.

In this chapter we have performed an analysis of various factors which are important to the design of socio-ecological indicators. The next steps will be to suggest and evaluate specific indicators.

(It has, after this work was completed, come to our knowledge that an extensive discussion on the theme of this chapter is also performed by Opschoor and Reijnders [1991]).

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