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Abstract: Discusses the interaction between socio-economic systems and their natural environment, by examining the indicators of sustainable development. Areas covered by the operationalization of sustainable development indicators; Details on the global nature of environmental problems; Important strategy of the operationalization of sustainable development; Link between economic data and ecological indicators.

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LANDSCAPE-RELEVANT INDICATORS FOR PRESSURES ON THE ENVIRONMENT

ABSTRACT The operationalization of 'sustainable development' requires indicators which can serve as information tools for the appraisal of the environmental consequences of socio-economic development. These indicators of sustainable development should cover three main areas: (1) pressures which the socioeconomic system exerts on the environment; (2) the state of the environment; and (3) socio-economic respomes, i.e. activities to alleviate environmental problems. In this article we discuss indicators for sustainable development based on two approaches for the description of the interaction between socio-economic systems and their natural environment: (1) socio-economic metabolism, i.e. the mode in which societies organize their exchange of matter and energy with their natural environment; and (2) the colonization (nature, defined as the conundrum of strategies employed to transform parts of the environment in order to render them more useful for societal needs. We focus on pressure-indicators which should be relevant for the development of cultural landscapes. Such indicators have to focus on the sectors agriculture, forestry, construction, and tourism. Four empirical examples for indicators of sustainable development are presented for the case of Austria: nutrient balances, manure management, energy consumption of crop farming, and appropriation of net primary production. These and similar indicators can be the basis for the development of spatially disaggregated sectoral ecobalances which are necessary for an integrated economic and ecological assessment of the economic branches with the highest relevance for the sustainable development (cultural landscapes.

Introduction

The global nature of environmental problems ('global environmental change') has been Widely recognized and has served as a crystallization point of environmental concerns in the last decades (Dunlap and Catton, 1994). The notion of sustainable development has proved to be extremely fruitful in stimulating and provoking a dialogue between various scientific disciplines from the natural and social sciences as well as between conflicting social groups. This indisputable success notwithstanding, there obviously is an urgent need for the operationalization of the concept of sustainable development. The number of definitions of sustainable development is large and grows relentlessly. For example, Pearce et al. (1990) collected 25 different definitions of sustainable development, and many more can be found in the literature. Given this heterogeneity, it appears to be difficult to judge if there is progress towards sustainable development or not, if current policies are successful, and if measures taken so-far have the desired effect.

One important strategy for the operationalization of sustainable development are sustainability indicators. The term indicator traces back to the Latin verb indicare, meaning to disclose or point out, to announce or make publicly known, to estimate or put a price on (Hammond et al., 1995). Indicators of sustainable development have three main functions (Bossel, 1996; Moldan et al., 1997): (1) simplification--they supply the user with information on the state of a system which is too complex to be assessed or measured directly; (2) quantification; and (3) communication. The development of indicators of sustainable development appears to be decisive for progress towards sustainable development (Moldan and Billharz, 1996).

In the meantime the importance of such indicators is widely acknowledged and there is considerable international effort in this area. There are several international initiatives for the development of sustainability and environmental indicators: various bodies of the UNO work on indicators of sustainable development (Moldan et al., 1997). The OECD develops environmental indicators (OECD, 1994). Within the EU, the European Statistical Office, Eurostat, is working on indicators for the environmental pressure which socioeconomic activities exert on the environment (Jesinghaus, 1997), while the work of the European Environmental Agency is focused on indicators for the state of the environment. The world bank too is attempting to develop definitions and measures of sustainability (Munasinghe and Shearer, 1995).

Indicators present information in quantitative form and allow the description of complex social, political, public, or natural processes. They thus can be seen as an empirical model of reality (Hammond et al., 1995; Bossel, 1996, Morrey, 1996). Indicators of sustainable development should describe progress towards sustainable development, a political goal which is connected to properties of society-nature interactions: socio-economic behaviour towards the environment is called 'unsustainable', if it triggers changes in the state of the environment which are detrimental to society (e.g. climate change, contamination of the environment, loss of biodiversity). Indicators of sustainable development thus--implicitly or explicitly--reflect some model of the interaction between societies and their natural environment. An ample diversity of such models can be found in the literature (for a review see Haberl et al., 1997). We believe that the pressure-state-response scheme of the OECD (1994) is most appropriate as a starting point for indicator development (see Fig. 1). The pressure-state-response scheme distinguishes three levels of analysis of environmental problems. One may ask (1) which pressures a society exerts on the environment (indicators for pressures on the environment), (2) how good or bad the state of the environment is (state indicators), and (3) which measures a society undertakes to improve either the environment (repair strategies) or its behaviour towards the environment (response indicators). The pressure-state-response scheme implies a (cyclical) cause-effectrelationship and is currently widely used by regional, national, and international organizations (UNO, ECE, OECD, EU).[1]

Direct links between economic data and ecological indicators can only be established for pressure and response indicators, because only they describe environmental aspects of economic activities--state indicators describe the 'well-being' of natural systems. Although all three types of indicators are necessary for the development of strategies for sustainable development, this paper focuses on spatially relevant pressure indicators. We report findings from an on-going project within the framework of the Austrian research focus 'Cultural Landscapes' ('Kulturlandschaftsforschung') aiming at the development of indicators which identify pressures relevant for the sustainable development of cultural landscapes ('Kulturlandschaften'), contribute to regional planing processes, e.g. spatial planing, and to the development of economic and environmental policies. In order to be policy-relevant, it must be possible to link the indicators to economic activities. Thus the possibility to achieve these interlinkages is an important goal in the process of designing such indicators. Economic activities which are of outstanding importance for cultural landscapes are agriculture, forestry, the building sector, and tourism. In Central Europe there exist practically no landscapes which are not, in one way or the other, influenced by the activities of these sectors (Bittermann, 1995).

These goals are ambitious, because good concepts and theoretical foundations for spatially relevant pressure indicators are lacking throughout the bulk of the international indicator literature. For example, the weakest parts of the pressure indicator systems of the World Resources Institute (Hammond et al., 1995) and the Eurostat {Jesinghaus, 1997) clearly is the policy issue of biodiversity loss. In this field there is an obvious lack of sound theoretical as well as telling empirical approaches for pressure indicators. One reason for this may be that the concern for the sustainable development of cultural landscapes often stems from the point of view of nature conservation which traditionally is more oriented towards evaluating and protecting the 'ecological value' of specific sites or landscapes. While we are well aware of the fact that we cannot offer more than 'work in progress', we believe that the theoretical and empirical discussion below may stimulate the discussion on this important issue.

Metabolism and colonization: concepts for the interaction of societies and nature

As described above, the development of indicators of sustainable development requires a concept of the relationship between societies and their natural environment. The concepts put forward in the indicator literature, however, often are rather based on ad-hoc considerations, follow the existing database, or are not even elaborated at all. We will here outline a theory-guided interaction model for the conceptualization of the society-nature interrelationship. This model has been developed by the department of social ecology at the IFF, an interdisciplinary team with members from social and natural sciences and seeks to bridge social and natural sciences, cutting across various disciplines in both realms (Fischer-Kowalski and Haberl, 1993, 1997; Fischer-Kowalski et al., 1997; Fischer-Kowalski, 1997).

The basic consideration of this interaction model is that, if human societies influence natural systems and vice versa, then society must not be conceptualized as a purely symbolic system (e.g. as a system of communication, Luhmann, 1986). There must be some sphere of overlap which makes possible interaction processes between nature and society. It is possible to explain interactions between symbolic and material systems, if we envisage society as a system of second order, comprising a (symbolic) cultural subsystem and a material compartment. This material compartment at least encompasses the population, i.e. the human bodies. For reasons which we will discuss below, it is useful to include artifacts and livestock into this material compartment of society. By doing so, we can define two systems, the material world on the one hand, and society on the other. The material compartment of society is part of both systems and is influenced by natural as well as cultural forces. If we conceptualize the society-nature relationship in this way, we are also enabled to analyse physical exchange processes between the material compartment of society and their natural environment (Fischer-Kowalski, 1997).

This approach does not fit within the paradigm of human exemptionalism' predominating the social sciences (Carton and Dunlap, 1978; Dunlap and Carton, 1994). It is a provocation for sociologists, who prefer to conceptualize societies as systems of communication (e.g. Luhmann, 1986). On the other hand, we can not envisage a way of analysing problems of global environmental change or sustainable development, if we do not offer some possible explanation, how society may influence nature and vice versa. Thus we believe, together with prominent environmental sociologists (Carton and Dunlap, 1978; Dunlap and Carton, 1994), that the paradigm of 'human exemptionalism' has to be abandoned if sociology is to play an important role in the analysis of current environmental problems. Moreover, this materialistic conception of society is needed less for materialistic cultural anthropologists (e.g. Harris, 1991) and human ecologists (e.g. Nentwig, 1995).

Of course, a materialistic conception of society or its compartments poses the problem of defining a theoretically plausible and operationally practical boundary of society vis-avis its natural environment. One of the guidelines in this respect is the understanding of society as an autopoietic system that generates its own boundaries. A possible concept for this is the assumption that the material compartment of society may be distinguished from other material objects by the human labour expended for their creation and maintenance (Fischer-Kowalski et al., 1997).

This interaction model of society and nature makes possible some conclusions for the operationalization of sustainable development. Societies, as the 'modus vivendi' of the species Homo sapiens, have to be organized in a way that sustains an exchange of matter and energy under given environmental circumstances. This at least must fulfill the nutritional requirements of the human population, but may surpass this lower limit by several orders of magnitude in complex societies using demanding technologies and keeping a large number of livestock. Obviously there existed and continue to exist numerous historically and regionally different types of social organization fulfilling these requirements and others that did or do not. All societies so far were not 'sustainable' insofar as they did trigger changes of their natural environments that in turn forced or at least stimulated changes within societies.

Thus for the operationalization of sustainable development we have to look at the material and energetic relations between society and nature. We find it useful to distinguish two kinds of relations: socio-economic metabolism and colonization of nature. Socio-economic metabolism is the mode in which societies organize the exchange of matter and energy with their natural environment: the input of resources and the output of wastes and emissions. Colonization of nature is defined as the conundrum of social activities which deliberately intervene into natural systems in order to render them more useful to society.

Socio-economic metabolim

Essentially, metabolism is a biological concept which refers to the internal processes of a living organism. Organisms maintain a continuous exchange of materials and energy with their environment to provide for their own functions, for growth and/or reproduction. In an analogous way, social systems convert raw materials into manufactured products, services and, finally, into waste and emissions--processes which economists describe as production and consumption (Ayres and Simonis, 1994).

The analysis of society's metabolism provides a kind of framework to distinguish cultures, societies or regions according to their characteristic relationship with nature. The overall 'size' of this metabolism can be described with regard to the following two aspects:

(1) Material flow. The socio-economic metabolism may be measured as mass throughput [kg yr[-1]] used for nutrition, shelter, clothing, buildings, etc. Every society has at least the metabolism that corresponds to the sum of the biological metabolisms of its population.

(2) Energy. Like any other dynamic system of material stocks and flows, social systems are driven by an energy flow which may be measured as energy throughput [J yr-1]. Every society has at least the energy turnover corresponding to the sum of the biological energy requirements of its members. Nowadays, in industrial societies the energy input per capita amounts to more than 40 times the biological energy requirement of humans.

The metabolism of a human society at a certain time in a certain region may be characterized by its mass and energy input. The input per capita and year is largely determined by the mode of production and the lifestyle associated with it. It is the size of the population, then, that determines the overall input of both energy and mass. On the other hand, the sustainable population density is determined by the mode of production, by a society's ability to exploit certain key resources, and by its ability to influence the properties of essential natural systems in the process of colonization (see below).

As each human being has a metabolism, the metabolism of a society has to be at least the sum of the metabolisms of its members. The history of mankind is a history of expansion of social metabolism far beyond this total of individual metabolisms. This process can be traced from hunter-and-gathering societies to agrarian societies and finally industrial societies. For this analysis it is useful to distinguish a 'basic' from an 'extended' societal metabolism. Basic societal metabolism exdusively uses resources available in actual natural cycles ('renewable resources'). Its outputs thus may be recycled naturally, and its output problems remain local, or regional at most (e.g. the removal of feces from densely populated cities) but do not cause problems of long-term sustainability. Basic metabolism, of course, does not necessarily mean sustainable behaviour. Locally and regionally an overuse of 'renewable' resources may well cause changes detrimental to human survival. Extended metabolism is the use of resources outside the range of actual biospheric cycles, such as fossil fuels, metals and many other minerals, in other words the so-called nonrenewable resources. These resources are more or less alien to 'normal' biospheric cycles or at least brought into them in excess. They cannot be 'naturally' transformed into nutrients for the next round, but strain the absorption capacity of the natural environment (Fischer-Kowalski and Haberl, 1997). Sustainability problems associated with this type of metabolism may occur with the input side (resource scarcity) as well as with the output side (pollution, wastes).

One possible application of this concept is the development of material flow accounts, a project which has been started in many industrial countries. These accounts look at the amount of materials extracted from nature, used and transformed in one way or another within society, and returned into natural cycles as wastes or emissions. In the first place, this is a more or less simple input-output calculation in material units (tons) which can be computed--on the basis of some methodological assumptions and conventions that are gradually being agreed upon internationally (Ayres and Simonis, 1994; Adriaanse et al., 1997; Bringezu et al., 1997)--from standard economic statistics. This results in a kind of material 'national product', with tons rather than money serving as accounting units. Divided by the size of the population we may analyse the 'characteristic metabolic profile' of societies. For current industrial societies, these per capita values are very similar (Janicke, 1994, see below).

As Austrian (Huttler et al., 1996) and German data (Bringezu and Schiltz, 1996) show this throughput consists to about 95% of water and air and only to about 5% of other material inputs. In Austria the water use per inhabitant and year amounts to about 500 tons per capita and year (t cap-1 yr-1), which is more than one ton per capita and day. The input of air is about one order of magnitude smaller and is about 40 t cap-1 yr-1. The high consumption of water and air is a generic characteristic of industrial metabolism and a direct consequence of the energy intensity of this mode of production: large amounts of oxygen are consumed in technical combustion and released into the atmosphere as H[2]0 and GO[2] (combined with the hydrogen and carbon content of fuels). The high water consumption is partly due to the cooling of engines (about half of the freshwater input serves that purpose in Austria).

In terms of pressures on the environment, the demand for air seems to be irrelevant if we focus on the input side: there is no reasonable concern about a possible scarcity of oxygen. The metabolic output, however, is highly relevant. For example, CO[2] is an important challenge to the global climate. Freshwater, on the other hand, is a very scarce resource in many parts of the world and is not available everywhere in the required amounts. Its extraction from exhaustible fossil groundwater sources, or--requiring a very high energy input--from seawater, generate environmental problems of their own. Even in waterrich countries like Austria, the procurement of water may cause considerable disturbance of natural water regimes.

If we focus on the raw materials input in a more narrow sense of the word, we may note that 'non-renewable resources' make up for at least half of the input in industrial metabolism? Table 1 presents the raw materials input for five industrial countries. While there still seem to exist some methodological inconsistencies hampering international comparability, the numbers and distributions are similar enough to support a concept of a 'characteristic metabolic profile' of the industrial way of life. It amounts to a resource consumption of about 20 metric tons per inhabitant and year. This is equivalent to a daily resource input of about 60 kg cap-1 yr-2 or about the average body weight of a member of the population. This material is divided up more or less evenly between energy carriers (that is biomass, as the renewable fraction, and fossil energy carriers such as coal, oil and natural gas), on the one hand, and metals and minerals on the other hand. While much of the energy carriers is used and transformed very quickly, and is then discharged to the environment (mainly to the atmosphere as H[2]0 and CO[2], but also as manure and wastes), at least half of the metals and minerals supposedly is added to the existing stock of socioeconomic infrastructure, e.g. roads, buildings, and other long term uses (Bringezu and Schutz, 1996; Huttler et al., 1996; Adriaanse et al., 1997).

For water, input equals output, given any reasonable level of accuracy. Air, too, is not stored within the society, but the gaseous output surmounts the air input because of the carbon and hydrogen of the fuels which is released into the atmosphere in form of carbon dioxide and water together with some quantitatively less important gases as for example SO[2]. This is different for the input of raw materials: at least one-third of these is put 'on stock', mainly in the form of buildings. The rest, however, is rendered back to nature as wastes and emissions into air, water and soil.

On the basis of these considerations, the amount of material turnover per year may be looked upon as an overall indicator for resource extraction from nature and gives some indications on the yearly output of a society in the form of wastes and emissions. It gives an admittedly crude, but instructive picture on the environmental pressures which a society exerts each year on its natural environment.

These analyses can be used to treat--among others--the following questions: It may be useful to ask, if material flows grow at the same rate as the gross domestic product (GDP) or if they grow faster or slower. It may be asked, which role recycling can play as an instrument to reduce raw material input. It may be investigated in detail, which levels of resource use are acceptable from an environmental point of view for which materials. From such studies, goals for the reduction of the use of some materials may be derived (e.g. Weterings and Opschoor, 1992). It may be asked, which societal 'driving forces' are responsible for the increase of resource input. The analysis of material flows also provides a useful framework for the development of comprehensive emission and waste monitoring systems, since it gives some consistency control (the sum of outputs and net stock increase must by definition equal the inputs).

As can be seen, the concept of societal metabolism provides a useful framework for many issues which are of key importance for sustainable development. It may be further differentiated to single branches of the economy and to fields of activity, e.g. food production or construction (Huttler et al., 1996, Schandl and Zangerl-Weisz, 1997).

The colonization of nature

The analysis of society-nature interrelations remains incomplete, however, if it is restricted to material input-output relations. For the analysis of the development of cultural landscapes this is immediately evident. Of course, agricultural inputs of a society are counted within material flow analyses. The environmental effects of agriculture, however, are not simply a function of the amount of materials extracted from nature. Agriculture relies on a strategy to replace a natural ecosystem with a managed one which yields much higher outputs of the kinds of materials which are useful for a society and less of those which are not. Thus we have to employ the concept of colonization of nature to investigate the related processes.

In order to maintain their metabolism, societies deliberately transform natural systems in a way that tends to maximize their usefulness for human purposes. For example, natural ecosystems are covered with concrete to provide even surfaces which greatly enhance transportation capabilities. The genetic code of species is altered in order to increase resistance against pests, or in order to produce pharmaceutics. We have called this type of intervention into natural systems 'colonization' (Fischer-Kowalski and Haberl, 1993). Colonization may be defined as the conundrum of social activities which deliberately change important parameters of natural systems and actively maintain them in a state different from the conditions that would prevail in the absence of human interventions. The notion colonization refers to the circumstance that societies transform natural systems into colonies in which many important parameters are regulated by deliberate planning and intervention strategies that had previously been self-regulated. Thus colonization requires a significant amount of socio-economic effort in the form of labour, technology, resources and quite a lot of knowledge about the affected natural systems and their regulation mechanisms.

The primary paradigm of 'colonization' is, of course, agriculture. Natural ecosystems produce only small amounts of food suitable for humans and their livestock compared to their overall biomass production. Agriculture seeks to maximize the amount of 'useful' biomass by the promotion of plants which allow for high yields of digestible biomass and a reduction of all other plant species. This requires a highly coordinated set of interventions, e.g. fertilization, breeding of varieties with high yields, control of herbivores, treatment of the soil etc.

Colonization affects many natural systems. Social activities which deliberately transform natural systems can intervene on different levels. The most traditional interventions take place on the level of biotopes: besides agriculture, transformations of the water household (construction of dams, straightening of watercourses etc.) intervene on this level. But the interventions may also take place on levels below, such as the level of organisms or even the level of genomes, which means an intervention into biological evolution (such as traditional breeding or modern biotechniques). We have tried to define such interventions more precisely both on a theoretical and on an operational level--but a lot of questions still remain unresolved (Fischer-Kowalski et al., 1997).

Colonization always tends to influence the rate of reproduction of 'renewable' resources, both in an intentional and in a non-intentional way. Cultivating, growing and fertilizing crops in agriculture for example does have the intended consequence of generating more biomass of a certain kind, and less of other kinds. But it also has the partially unintended consequence of reducing biodiversity and reducing the natural genetic variation of plants. A problem of this kind discussed more often is the contribution of agriculture to the loss of soil (erosion). Thus obviously sustainability problems (and chances) of societies may not only arise from their metabolism, e.g. the overuse of resources, but from behaviour that influences the self-regeneration of resources, the 'productivity of nature'. While colonization may be the prerequisite for the survival of a population on a given territory, it also may cause environmental problems which have been put on the agenda by social movements, e.g. nature conservationists, the animals-rights movement or, more recently, people concerned about the possible effects of genetic engineering.

On the other hand, which colonization strategies a society employs makes a lot of difference for its social, cultural and economic organization. Colonization of natural systems in all cases requires a high degree of organization of human labour, and probably it also means an increase in the overall amount of labour to be spent. On the other hand, it allows for a higher population density in a given natural environment.

There is a wide variety of colonization strategies which would deserve further research. Until now, we have succeeded in the operationalization of two empirical indicators which will be described below (appropriation of net primary production, nutrient balances). These indicators show how much societies intervene into ecological energy flows and natural nutrient cycles.

Empirical examples for landscape-relevant indicators of sustainable development

The policy relevance of sustainability indicators will depend on many features, one of the most important being the possibility to link them to the behaviour of actors that actually can be influenced by suitable policy instruments or measures. As we develop spatially relevant indicators, we have to focus on those actors that are most directly connected to the development of landscapes. While all economic sectors influence the development of landscapes to some extent, some are of outstanding importance. The branches we believe to be most important are agriculture, forestry, tourism and the construction sector. Of course, it is not possible to analyse these sectors isolated from the rest of the economy: there are manifold connections between these and other sectors of the economy. For example agriculture is connected to the manufacture of food and beverages and to the wholesale trade of agricultural raw materials and living animals, to name but a few. These environmentally and socially relevant flows into and from the investigated sector to other branches of the economy must be considered.

Currently studies are carried out on three sectors, namely agriculture (Bittermann, 1990, 1991a, b, 1995), forestry (OSTAT, 1992; Bittermann, 1993b; Bittermann et al., 1993; OSTAT/FBVA, 1995) and tourism (Bittermann, 1993a, 1994b). These studies aim at the development of pressure indicators on the basis of statistical data on selected socioeconomic activities which potentially may have negative impacts on the environment as well as social impacts. Future efforts will attempt to combine these activities with natural and social conditions in order to make it possible to discover environmental risks and potential social disturbances at a regional level. This is of great practical importance. If all interrelating factors are known, it is not necessary to examine all parameters on the spot-it suffices to focus on a few selected ones. This greatly reduces cost. Basically, it provides indicators for risks (i.e. potential hazards). The advantage of this approach is that before any of the expected negative effects actually occurs, the respective measures can be taken (Bittermann, 1996).

In what follows we present three environmental pressure indicators for the sector agriculture--nutrient balances, manure management and energy consumption in crop farming--and one cross-sectional indicator, appropriation of net primary production. Two of the indicators are linked to the concept of metabolism and to the capability of a society to safely handle its off-products. The indicator 'energy consumption of crop farming' shows the amount of fossil energy invested in agricultural production and relates the output in form of edible biomass to the inputs which are necessary to produce it. The relation of the storage capacity for manure to livestock density (indicator 'manure management') shows, where the livestock feces can be safely stored and where severe emission problems are likely to occur. The other two indicators rely on the approach of colonization: nutrient balances show, how the natural nutrient flows are manipulated and controlled by a society in order to maximize yields. The appropriation of net primary production is an indicator for the socio-economic utilization of space on the one hand and the natural productivity of ecosystems on the other.

Energy use in crop farming

Energy use in crop farming is an important part of the energy input of agriculture (see Fig. 2). It is therefore connected with the main share of agriculture's direct contribution to the greenhouse effect (CO[2] emissions) and air pollution (NO[x], particle, and CO emissions) as well as resource depletion due to crop farming (non-renewable fuel consumption). It is thus a good indicator for agricultural sustainability. Energy use in crop farming is calculated on the basis of land-use types and average fuel quantities necessary for their cultivation.

Manure management

As we define it, the indicator 'manure management' relates the storage capacity for liquid manure to livestock density. The indicator shows whether the animal manure of livestock can be stored with a minimum of environmental impacts or not. If there is not sufficient storage capacity--in Central Europe it should be possible to store the manure for 4 to 6 months--it is likely that the manure has to be spread under conditions which cause negative environmental impacts. For example, if liquid manure is applied on black fallow, a large part of the nitrate content will leach into the groundwater. If it is spread on frozen soils or on snow layers, the nutrients will pollute the adjacent watercourses during the following thaw. In Austria, this occurred in many regions during the long and cold winter 1995/96. The application of manure during dry seasons leads to air pollution. Moreover, unsuitable storage of liquid manure also contributes to the avoidable risk of ammonia and methane emissions. Figure 3 gives an overview of the relation between storage capacities and livestock densities over a six-month period on district level.

Nutrient balances

In principle, the establishment of nutrient balances relies on the calculation of the difference between the input of nutrients (mineral fertilizers, fodder crops, dung, etc.) on some agricultural area and the output, i.e. the nutrient content of the harvested crops).[3] Nutrient balances--mainly those of the most important plant nutrients nitrogen and phosphorus-are suitable indicators for different environmental problems related to agriculture (Hessen et al., 1997). If the equilibrium between input and output of nutrients is disturbed over some years or even decades, nutrients will leak into groundwater (nitrate), surface water (phosphate and nitrate), and the atmosphere (N[2]O). Nutrient balances furthermore are an important instrument to estimate the relation between material and energy input and exploitable output. This is one of the most important figure for the evaluation of agricultural sustainability. Figure 4 shows the nitrogen balance for Austria on the level of districts as an average of the period 1988 to 1994. Figure 5 does the same for phosphorus.

Appropriation of net primary production.

Net primary production (NPP) is the net biomass production of green plants at a defined site within one year. In the process of photosynthesis, green plants convert solar energy to chemically stored energy in form of biomass. This biomass is the basis of all food chains and thus is the main energetic basis of all heterotrophic organisms. Thus NPP is the nutritional basis for the diversity of animals and other organisms which are not capable of converting solar energy into chemically stored energy as a basis of their metabolism.

The socio-economic appropriation of net primary production is defined as the difference between the amount of NPP which would be present in the absence of human interventions (i.e. the NPP of the potential, undisturbed vegetation), and the amount remaining in actual ecological cycles. The latter figure can be calculated as the NPP of the actual vegetation minus harvest in form of agricultural biomass and wood (for reference see Haberl, 1995, 1997).

Two main processes contribute to the appropriation of net primary production.

1. The alteration of ecosystems: if houses, roads etc. are built, no NPP can occur. Other interventions reduce the NPP per unit area, for example if a forest is converted to a meadow. Some other interventions also may increase NPP per unit area, e.g. some crops are more productive than the natural ecosystems.

2. Harvest: Products of photosynthesis are harvested by a society and thus are not available as energetic input for heterotrophic food chains.

For Austria, the appropriation of above-ground NPP has been calculated on the basis of statistical data for the year 1990. Of the 1.501 PJ yr-1 which would be available in natural ecosystems if human interference were absent, only 884 PJ yr-1 can actually serve as energy input of all heterotrophic food chains: the above-ground NPP of the actual vegetation falls short from that of the potential vegetation by 105 PJ yr-1. Society additionally harvests some 512 PJ yr-1 (Haberl, 1997). This does not only show the magnitude of the societal interventions into the natural energy flow of ecosystems. NPP appropriation may also have negative effects on biodiversity. The so-called species-energy hypotheses predicts that a reduction of energy flow may contribute to a reduction of species diversity (Vitousek et al., 1986; Wright, 1990).

Figure 6 shows that the intensity of the socio-economic appropriation of aboveground net primary production is correlated with the intensity of agriculture and the density of the built infrastructure. Figure 6(a) shows the above-ground NPP of the potential vegetation. Figure 6(b) the above-ground NPP of the actual vegetation. Figure 6(c) reveals the homogenizing effect of NPP appropriation on the amount of biomass energy remaining in nature. The reason for this is that the level of NPP appropriation in low in the sparsely populated Alps, while it is highest in intensively used agrarian landscapes and densely populated cities. The possible effects of this intervention and conclusions for sustainable development are to be discussed in an on-going research project (Haberl et al., 1997).

Sectoral ecobalances: a combined economic-ecological reporting system

Pressure indicators and indicators of sustainable development in general can be used for many purposes (see below). One important application is the development of reporting systems which aim at monitoring the environmental 'behaviour' of economic sectors. The Austrian Federal Statistical Office OSTAT has developed such reporting systems called 'sectoral ecobalances' (Bittermann, 1994a; Bittermann and Gerhold, 1994). A sectoral ecobalance (Fig. 7) may be defined as a compilation of environmental data or indicators which describe the environmental pressures and--to some extent--the responses of an economic branch and give some information on its effects on social structure. Sectoral ecobalances aim at linking economic data with data on the environmental and social impact of economic branches at the regional level. Data are compiled in a way which combines compatibility of the economic component with national accounts and quantify the related pressures on the environment. Sectoral ecobalances rely on data which can be quantified in physical units. A valuation--the integration of qualitatively different impacts in indices on the basis of valuation factors--may follow as a second step, but is not part of a sectoral ecobalance.

In theory, the most powerful tool to analyse the regional interactions between environmental, economic and social impacts would be 'regional ecobalances'. These would indude all socio-economic activities and their links to the environment. In practice, however, it is seldom possible to establish such overall balances due to the complexity of these interactions and of the environmental phenomena. Furthermore it is difficult to quantify the proportion of 'home-made' vs 'imported' environmental stress. The database on the state of the environment is often very inhomogenous, and state indicators often do not exist at all at the regional level. The procurement of such indicators would require a dense monitoring network which only is available for some aspects like quality of air and of flowing water. Regionally dis aggregated sectoral ecobalances are thus an important step towards comprehensive regional ecobalances. While a sectoral ecobalance does not include indicators on the state of the environment, the specific natural conditions within the region under consideration may be taken into account within the process of indicatordevelopment.

The most important feature of sectoral ecobalances is that the indicators are formulated in a way which guarantees the compatibility of the sector definitions with those of economic accounting and reporting systems. As the most important economic reporting system is the System of National Accounts (SNA), the sector definitions should correspond to the NACE rev. 1 classification (OSTAT, 1995). To allow the development of ecological indicators with reasonable effort, the classification (NACE 1 to 5 digits) has to be flexible enough so that more or less homogenous groups with respect to the consumption of resources and stress potential can be defined (Bittermann, 1994a). Of course, the interrelations between economic sectors also have to be taken into account.

Sectoral ecobalances can thus be used to relate the economic importance of the sector under consideration with its environmental impact on the regional level. They are therefore an important tool to describe socio-economic pressures on cultural landscapes and develop suitable policies to avoid or alleviate them. Sectoral ecobalances are fully compatible with international efforts, for example the indicator systems currently developed by the OECD, the EU, and the Economic Commission for Europe of the UNO (ECE).[4] They can be used for the following purposes: (1) for the development of models of an economic sector which are able to simulate the effects of sector-related economic and environmental policies; (2) to estimate the environmental effects of different strategies of regional development; and (3) as an information basis for the economic optimization of strategies of sustainable development.

Conclusions

Landscapes have many functions for industrial societies. They serve as production areas for agriculture and forestry, as industrial sites, or as residential areas. Raw materials are extracted from landscapes, water is diverted, the metabolic output of society has to be disposed or released into the rivers. The transport of materials, goods, people, energy, and information requires infrastructure and thus exerts various pressures on landscapes, e.g. roads, pipelines, high voltage grids, telephone cables etc. Moreover, landscapes are important for leisure, recreation, and tourism. They have a shelter function, e.g. protection against avalanches, mudflows, rockfall, or floods and, last but not least, they are important for the conservation of biodiversity and wildlife.

The potential of various landscapes to provide for these and many other possible functions differs greatly. For example, mountainous landscapes will have little potential as an agricultural production or residential area, but it may be important for recreation, forestry, and wildlife. While extensive land-use may allow the 'coexistence' of different uses, intensification often relies on enhancing one use at the cost of another. For example, intensively used agricultural areas or traffic zones will not be attractive as residential areas and threaten biodiversity. Intensification thus leads to an increased spatial differentiation of landuse, for example by the establishment of industrial sites separate from residential areas, or by the development of 'agricultural deserts' with little or no recreational or ecological value. On the other hand the declaration of areas for nature conservation--as a response to the loss of biodiversity--excludes agriculture and forestry on the respective areas.

Policies oriented towards sustainable development should promote multifunctional landuse patterns and try to find a balance between the different landscape functions. This has effects on the socio-economic metabolism and the corresponding colonization strategies. It appears plausible that diverse patterns of land-use, including a broad spectrum of colonization strategies--e.g, in a diverse pattern of fields, meadows, horticulture, forests etc.-will be more sustainable than monofunctional areas, e.g. huge 'agricultural deserts', solely oriented towards a maximization of agricultural yield. On the other hand, these landscapes will probably produce lower outputs of biomass, which in turn will have important repercussions on the socio-economic metabolism. In general, we believe that a massive reduction of the anthropogenic energy and materials turnover is a prerequisite for achieving sustainable land-use patterns.

Spatially relevant environmental indicators and sectoral ecobalances may be useful for the appraisal of the potential and actual functions of landscapes for human societies and the analysis of conflicts between different types of land-use on every spatial level. They may serve as information tool for the quantification of environmental pressures together with the economic importance of the spatially most important economic sectors and may thus help to objectivize the state of affairs in conflicts of interest.

We believe that the presented indicators, however preliminary they may be, can be used for the development of a system of sustainability indicators. We have tried to show the variety of indicators which can be developed on the basis of the concepts of societal metabolism and the colonization of nature. At present, the described indicators are only examples, since a comprehensive system of pressure indicators still has to be developed.

For the development of strategies towards sustainable development on the basis of such an indicator system the following steps may be useful: (1) identify relevant pressures on the environment, (2) find out which levels are environmentally acceptable, e.g. by developing sustainability levels on the basis of the ecocapacity concept, (3) forecast trends for the pressures and identify reduction targets (where a reduction appears to be necessary), and (4) develop socio-economic strategies for the realization of these reductions (Weterings and Opschoor, 1992). Although in most cases such sustainability levels still have to be defined, the development of pressure indicators is a prerequisite for this process which we believe to be essential for an operationalization of sustainable development.

Sustainable development will require a reorganization of the society-nature relationship. It is a project with profound impacts on the economy, societal institutions, and the everyday life of all members of the industrial societies. The day-to-day experience of modern societies, however, does not indicate an urgent need for radical change: raw materials are growing ever cheaper. Agriculture produces an excess of goods that can not be sold for regular prices. Social problems still can be alleviated by stimulating economic growth (Fischer-Kowalski and Haberl, 1997). Even some environmental problems-e.g. SO_2 emissions-have been significantly reduced. Sustainability indicators are essential to get an unbiased perspective on the quantitative and qualitative dimensions of the problem at stake:

Indicators of sustainable development are a powerful information tool which provide user-orientated pictures of sustainability changes and trends. Appropriately formulated information can promote sustainable development within existing communication and through patterns, thereby affecting decisions and shaping policies. (Moldan and Billharz, 1996, p. 5.)

The development of sustainability strategies requires the concentration of efforts on a strategic level. Sustainability indicators may be one important part of such a strategy.

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Notes

1. In the last years there has been some discussion on the notion 'pressures'. Some publications distinguish 'pressures' and so-called 'driving forces', i.e. social and natural trends which influence the pressures on the environment. Other authors replaced 'pressures' with 'driving forces' to avoid the negative smack of the former notion.

2. As the Wuppertal Institute and the World Resources Institute show (Schmidt-Bleek, 1994; Bringezu and Schutz, 1996; Adriaanse et al., 1997), there are large materials flows 'hidden' behind the direct material input of used materials. These 'hidden flows' never become commodities in the economic sense. They may consist of overburden from mining, excavation materials from construction, eroded soil or, as is sometimes argued, even the

amount of soil turned over in ploughing. Depending on their definition and the applied estimation methods, these 'hidden flows' can amount to twice as much as the 'used materials' (or 'direct material inputs' in the terminology of Adriaanse et al., 1997). On the basis of this definition, the 'total material requirements' of industrial countries can easily amount to more than 80 tons per capita and year (Adriaanse et al. 1997, p. 23).

3. Two different approaches exist to calculate nutrient balances. In the so-called field surface-stable approach the relation between nutrient input both of natural and anthropogenic origin to and output from the agricultural area due to the harvest is calculated. The so-called farm gate approach takes all relevant material flows into (fertilizers, fodder crops, etc.) and from the farm (all sold agricultural products) into account. Theoretically the results of both should be identical. We here are following the field surface-stable approach because it gives more detailed information about environmental risks.

4. The Green Accounting and Indicators Initiative of the EU commission is of high importance (DG XI et al., 1996). As a first step of this initiative the shares of pressure of the five sectors; agriculture, energy supply, industry, transport, and tourism, as defined by the 5th environmental action programme (Koinmission der Europaischen Gemeinschaft, 1992) complemented by waste management on ten environmental problems (defined by the Commissions Scientific Advisory Groups) shall be detected and sectoral indicators for these pressures shall be developed (Sectoral Infrastructure Projects). Then by passing the so-called Emission Structure Information System the indicators' database shall become standardized. In a following third step the standardized and synthesized data can be evaluated in different ways.

Table 1. The characteristic metabolic profile of industrial societies: domestic use of materials (i.e. domestic extraction plus imports minus exports) in 1991. The table only includes used materials, excludes air and water and 'hidden flows' (overburden, erosion) and excavation materials

	Austria	Japan	W. Germany (1990, before unification)
Biomass	5.6	1.4	3.3
Oil, coal, gas	3.0	3.3	4.9
Metals, minerals, others	11.2	11.7	10.5
Total domestic consumption	19.8	16.4	18.5
Population (in millions)	(7.8)	(124.8)	(63.2)

	The Netherlands	USA	Unweighted arithmetic mean
Biomass	10.2	3.1	4.7
Oil, coal, gas	6.4	7.7	5.1
Metals, minerals, others	6.4	8.9	9.7
Total domestic consumption	22.4	19.7	19.5
Population (in millions)	(15.0)	(252.3)	(5 countries)

Sources: Adriaanse et al. (1997), Schandl (1997).

MAP: Figure 2. Energy use in crop farming in TJ by districts, 1990.

MAP: Figure 3. Manure management by districts, 1990. Balance of storage capacity and live-stock effluents related to a 182 days storage period.

MAP: Figure 4. Five years' average nitrogen balance (1986-1990) for intensively used agricultural land in kg N ha[-1] by districts.

MAP: Figure 5. Five years' average phosphorus balance (1986-1990) for intensively used agricultural land in kg P[2]05 ha[-1] by districts.

MAPS: Figure 6. The spatial differentiation of NPP appropriation in Austria. NPP appropriation has an 'homogenizing' effect on the availability of energy in terrestrial ecosystems (see text for explanation).

DIAGRAM: Figure 7. The concept of sectoral ecobalances.

DIAGRAM: Figure 1. The pressure-state-response scheme.

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