Sustainable development: socio-economic metabolism and colonization of nature

Marina Fischer-Kowalski and Helmut Haberl*

1. Introduction

The emergence of 'sustainable development' as a key concept in the debate surrounding environmental issues has stimulated an interdisciplinary dialogue which has brought together scientists from most divergent fields as well as conflicting political and social groups. The concepts of socio-economic metabolism (basically the material input, processing and releases of societies and the corresponding energy turnover) and colonization of nature (activities which deliberately alter natural systems in order to render them more useful for society) we are presenting below are attempts to relate the notion of 'sustainable development' to core characteristics of society, in a historical perspective. We also hold that these concepts can be helpful to identify and operationalize targets of and strategies towards sustainable development.

The analysis of the metabolism and the colonization strategies of different types of society, distinguished by their modes of production, their technologies, and their way of life, provides, as we will try to demonstrate, a useful framework for the discussion of the socio-economic and cultural reasons of environmental problems. It leads to the conclusion that – independent of population growth – the scale of the per-capita metabolism of industrial societies has to be tackled by strategies of 'sustainable development', and that such strategies can only be developed if the economic, technological, and cultural variables within industrial societies influencing this metabolism and their interactions are properly understood.

We proceed as follows: Section 2 explains the notions 'metabolism' and 'colonization'. Section 3 gives an overview of the material metabolism of industrial societies, using data from Austria, Germany, Japan, the Netherlands, and the United States, and compares them with estimates for hunter-and-gathering-societies and agrarian societies. Section 4 then elaborates on the energetic metabolism of different types of society and relates this to colonization strategies and labour intensity. Section 5 deals with the feedback-mechanisms between societies and the natural systems they exploit and tackles the question why it is so hard for industrial societies to perceive their sustainability problems.

Marina Fischer-Kowalski and Helmut Haberl are with the Department of Social Ecology of the IFF, Seidengasse 13, A-1070 Vienna, E-mail: socec.iff@univie.ac.at. The main research interests of Marina Fischer-Kowalski, professor for social ecology, are directed to materials flow analysis, the cultural evolution of society-nature-interactions, and the interrelations of lifestyles, policies, and the environment. Helmut Haberl, biologist, works on energy and the environment, sustainability indicators, appropriation of net primary production, and the colonization of nature.

2. The concepts of 'metabolism' and 'colonization'

Essentially, metabolism is a biological concept which refers to the internal processes of a living

ISSJ 158/1998 © UNESCO 1998. Published by Blackwell Publishers, 108 Cowley Road, Oxford OX4 1JF, UK and 350 Main Street, Malden, MA 02148, USA.

organism. Organisms maintain a continuous flow of materials and energy with their environment to provide for their functioning, for growth and reproduction. In an analogous way, social systems convert raw materials into manufactured products, services and, finally, into wastes. This way of looking at the society-nature-interaction as a matter of physical exchange dates back as far as Marx and was revived with 'ecological economics' (Ayres and Kneese 1969, Boulding 1973). Similar ideas and concepts have also been used in UNESCO's 'Man and the Biosphere' (MAB) program for the analysis of the ecology of cities (e.g. Boyden 1992, Vester 1976).

The analysis of society's metabolism provides a framework to distinguish cultures, societies or regions according to their characteristic exchange relations with nature. First you can just look at the overall 'scale' of this metabolism with regard to the following two aspects:

(1) Materials throughput: The societal metabolism may be measured as materials throughput [$kg.yr^{-1}$] for nutrition, shelter, clothing, buildings etc. This of course follows the law of conservation of mass: The input per unit time equals the output (i.e. emissions, wastes) plus changes in stock. In the long run input equals output. The scale of a society's metabolism at least equals, but is typically much larger than the sum of the biological metabolisms of its population.[1]

(2) Energy throughput: Like any other dynamic system of material stocks and flows, social systems are driven by an energy flow. 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 typically amounts to more than 40 times the biological energy requirement of humans.

A society's materials and energy input per capita and year is largely determined by the mode of production and the style of life associated to it. We term this the 'characteristic metabolic profile' of a society. A social system's overall input of energy and mass is then its characteristic metabolic profile times the size of its population.

Beyond scale, qualitative distinctions have to be made. A society may live from the 'renewable resources' it can draw from the biosphere (or, even more narrowly, from its local or regional biosphere). This *'basic metabolism'* rests upon the natural reproduction of resources: freshwater, air, and plant or animal biomass. For each of these resources there exists a 'natural recycling mechanism' that transforms the releases from social metabolism into useable inputs again. Most societies in human history had nothing but such a basic metabolism. They could deplete their environment of resources if the rate of consumption exceeded the rate of natural reproduction. Their main environmental and 'sustainability problem', therefore, was resource scarcity.

An *'extended metabolism'*, in contrast, largely relies on the mobilization of resources from outside the biosphere, so-called 'non-renewable resources' such as fossil fuels, metals and other minerals from geological deposits. The notion of 'extended metabolism' is similar (but not identical) with Boyden's (1992) notion of 'technometabolism'. Huge stores of non-renewable resources exist and can be used at rates vastly surmounting their natural replenishment. Thus this extension of metabolism, in combination with technological innovation, is able to alleviate problems of resource scarcity, at least temporarily, i.e. until the geological deposits are exhausted. Unfortunately, however, new problems on the output side become more important: waste deposition and pollution.

Of course, outputs from renewable resources may also be environmentally detrimental, e.g. by causing hygienic problems or eutrophication. But the mobilization of materials that had been stowed away in subterrestrial sinks for geological time periods into the biosphere kicks off biogeochemical processes which may overcharge the capability of ecosystems for gradual evolutionary adaptation. As the globally mobilized amounts of materials increase exponentially, anthropogenic interference into natural biogeochemical processes becomes ever-more prominent. As for example Ayres and Simonis (1994) demonstrate, the amount of carbon, nitrogen, sulphur and phosphor mobilized by the societal metabolism of industrial societies ranges from five to several hundert percent of natural processes. While locally and regionally pollution problems have been known for a long time, global long term effects such as climate change and the ozone hole are novel consequences of the large-scale extended societal metabolism. As an aside we may note that the difference between a more or less basic and an exended metabolism is also mirrored in differences of perception of 'environmental problems' between the highly industrialized countries – who focus on problems of pollution – and the developing countries, who focus on scarcity of food and freshwater (Redclift 1993).

What is 'colonization' then? In order to maintain their metabolism, societies transform natural systems in a way that tends to maximize their usefulness for social purposes. Natural ecosystems are replaced with agricultural ecosystems (meadows, fields) designed to produce as much usable biomass as possible, or are converted into built-up space. Animals are domesticated, genetic codes of species are altered to increase their resistance against pests or pesticides, or to produce pharmaceuticals. Such interactions between social and natural systems cannot be understood as metabolic exchanges of matter and energy. They bear a different character. After the Latin term for peasant 'colonus' we termed this mode of intervention into natural systems 'colonization' and defined it 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 such interventions (Fischer-Kowalski et al. 1997).

Colonization can be viewed as a strategy to secure the future availability of natural resources. This strategy constituted the core of the 'neolithic revolution' – the 'invention' of animal husbandry and farming. Besides hunting for increasingly scarce deer, and gathering edible plants distributed over large areas, goats and sheep were captured and bred, and grains were sown on soil prepared for growing them in high concentrations. In the course of the last 10,000 years most human societies adopted such strategies – but often only under severe environmental pressure (Vasey 1992): Colonization means a considerable increase in human labour. The maintenance of colonized natural systems to keep them in a socially desired state implies the investment of a more or less continuous effort (and usually also materials). Moreover, the attempt to control some parameters of a natural system may involve social systems into a spiral of ever more demanding control efforts: Once crops are planted, irrigation must be organized. Once there is irrigation, soil salinity must be controlled by periodical flooding. To be able to do so, dams have to be constructed. To maintain these dams, a society must keep labourers and security forces, and so on. With every innovation, with every further step, the risk at stake is becoming larger (Sieferle and Müller-Herold 1996) and the neccessary efforts increase. To raise and maintain that continuous investment puts high demands on social organization.[2]

Intuitively one is tempted to conceive of 'colonized natural systems' spatially, as a difference between 'cultivated land' and 'wilderness'. While this concept may indeed be useful for the analysis of land-use and the spatial distribution of social activities, we prefer a sufficiently abstract notion of 'colonization'. Social activities which colonize natural systems may intervene on different levels. The most obvious interventions take place on the level of biotopes: agriculture and forestry deliberately transform biotopes in order to make them more productive for types of biomass society needs ('renewable resources'), and less productive for other biomass. Similarly transformations of the water household (construction of dams, draining, irrigation, etc.) intervene on this level. But the interference 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 biological techniques). We expect many links between the colonization strategies and the social organisation of societies. Historically it seems obvious that societies increasingly draw all their 'renewable' resources from highly colonized environments. The proportion of nutrition from non-colonized environments (i.e. 'exploitation' such as fishing, hunting and gathering) seems to decrease continuously,[3] as does for example the proportion of water utilized from 'wild' sources (as compared to water from technical structures).

The sustainability problem invoked by societal metabolism appears to be that its scale may exceed the carrying capacity of natural systems, be it in the supply of resources or the absorption capacity for wastes and emissions. By contrast, the sustainability problem involved with colonization, beyond its ecological effects (see section 4) is that it may exceed the 'carrying capacity' of the social system, that is the amount of available labour and/or organizational capacity.

3. Socio-economic metabolism under industrial conditions compared to other modes of production

As mentioned above, one can think of two reasonable ways to look at the scale of the metabolism of a society: It can be operationalized as materials or energy flow and may thus be counted as kilograms or Joules per year. Of course, the same material can be part of both flows (e.g. mineral oil), but some will only be relevant as a materials flow (e.g. gravel, sand), and others, such as electricity, may be materially irrelevant, but an important source of energy.

Materials are extracted from nature, used and transformed in one way or another within society, and are eventually returned into natural cycles as wastes or emissions. Using standard economic statistics, this can be accounted for in a more or less simple input-output calculation in material units [$kg.yr^{-1}$] on the basis of methodological assumptions and conventions that are gradually being agreed upon internationally (Adriaanse et al. 1997, Ayres and Simonis 1994, Bringezu et al. 1997). The result is a kind of material 'national product', with kilogrammes or tons instead of a currency serving as accounting unit. Divided by the size of the population, this figure provides a measure of the per capita metabolism of an average member of a society – the characteristic metabolic profile.

This characteristic metabolic profile may be used – as we will show below – to compare different modes of production (hunter and gatherers, agricultural societies) in a broad historical perspective. It can also serve as a 'quick and dirty' appraisal of the pressure which a society exerts on the environment. And it contributes to our understanding of the inter-relations between natural, social, and economic processes which are relevant to sustainable development (see section 5 of this paper).

One may, of course, challenge the presumption that the total material throughput of a socio-economic system is a reasonable measure of its pressure on the environment. If we go by the Austrian and the German data (Bringezu and Schütz 1996, Hüttler et al. 1996), this throughput consists of about 95% water and air and only of about 5% other material inputs. The high consumption of water and air is indeed 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 (much beyond what is needed for the breathing of humans and livestock, and biomass combustion in open fires under hunter-gatherer or agrarian conditions), and released into the atmosphere as H_2O and CO_2 (combined with the hydrogen and carbon content of the fuel). The high water consumption is 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 indeed a very scarce resource in many parts of the world (not, of course, in England, the motherland of the industrial mode of production), and will just not be 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. As a consequence, it seems clear that the socio-economic use of air and water does put serious pressures on the environment, even if these are not considered to be in the same proportion to their physical weight as with other raw materials.

Let us now disregard water and air, and focus on the raw materials input in a more narrow sense of the word (table 1). There, 'non-renewable resources' make up for at least half of the input in industrial metabolism.[5]

Industrial production of pigs, Los Baños, California, USA. Vincent Menzel/Cosmos

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

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 includes only used materials, excludes air and water and 'hidden flows' (overburden, erosion) and excavation materials.

	Austria	Japan	W. Germany (1990, before unification)	The Netherlands	USA	Unweighed arithmetic mean
Biomass	5.6	1.4	3.3	10.2	3.1	4.7
Oil, coal, gas	3.0	3.3	4.9	6.4	7.7	5.1
Metals, minerals, others	11.2	11.7	10.5	6.4	8.9	9.7
Total domestic consumption	19.8	16.4	18.5	22.4	19.7	19.5
(Population in millions)	(7.8)	(124.8)	(63.2)	(15.0)	(252.3)	(5 countries)

Sources: Calculated from Adriaanse et al. (1997) and Hüttler et al. (1997)

very quickly, and is then discharged to the environment (mainly to the atmosphere as H_2O 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 socio-economic infrastructure, e.g. roads, buildings, and other long term uses (Adriaanse et al. 1997, Bringezu and Schütz 1996, Hüttler et al. 1996).

The characteristic metabolic profile of industrial societies can be compared to the scale of metabolism which – using historical and anthropological data – can be estimated for other modes of production. For the Central European Region, we estimated the current metabolic profile to be about 40 times larger in scale than that of hunter and gatherers (including air and water). Contemporary industrial Europeans use about 10 times as much air, 20 times as much solid ‘raw materials’ and 60 times as much water.[6] Accordingly, each inhabitant of industrial society puts an amount of pressure on the natural environment which is several times larger than that of his or her predecessors’.

Figure 1 attempts a comparison of the material and energy input of hunter-and-gathering societies, an example from an agrarian society – Törbel 1875 – and the average consumption of the industrial societies for which we have data (see table 1). Törbel, a small village in Switzerland, has been investigated in an in-depth study by Netting (1981) which allows an estimate of its metabolic profile. A comparison of the three social formations yields a three- to fivefold increase in the scale of metabolism each time, both for the materials and for energy use.

The increase of metabolic scale from hunters and gatherers to agrarian societies is mainly a consequence of the different amounts of biomass required. This is mainly due to the changing socio-economic status of animals. For hunters, animals are booty (and food, clothes, tools etc. subsequently). The food they require comes from natural cycles. For farmers, animals are livestock, socio-economic property. They have to be fed, fenced in and housed, in order to be able to use their products for human nutrition, and their strength for performing physical labour. All the materials required for this have, of course, to be considered as part to the socio-economic metabolism. The village of Törbel as an Alpine village particularly depends on livestock: milk and cheese make up the most important part of the human diet in this agricultural example. A more vegetarian agrarian culture could be expected to live on a much smaller biomass-input (see for example the analysis of a contemporary rural village in India by Metha and Winiwarter 1997). Of course, agrarian societies also use minerals and other materials. But the amount is very small and was neglected in figure 1. Had we used a more urban agrarian example, their proportion might have been somewhat higher.

The increase in metabolic scale between agrarian and industrial society is mainly due to new components: fossil energy carriers and considerable amounts of minerals and metals. The biomass fraction shows only a small increase. Note, however, the considerable increase in the consumption of the ‘renewable’ resources air and freshwater discussed above. This marks the transition from a ‘basic’ to an ‘extended’ metabolism.

As a consequence, we may ask the following question: If human cultural development, or ‘progress’, is accompanied and possibly achieved by an increase in the per capita scale of the socio-economic metabolism of several orders of magnitude, how was this managed in the past, and what does this mean for the future? This question is even more intriguing, if we take into account that currently about 70% of the world population live under more or less agrarian conditions, striving for an industrial way of life.

4. Some reflections on energetic metabolism, the need for colonizing nature, and society’s labour intensity

The increase in scale of metabolism from hunter and gatherer to agrarian societies mirrors the invention of ‘colonization’, or, as Sieferle (1982) by a similar line of reasoning calls it, the transition from an ‘unmanaged’ to a ‘managed’ solar energy regime. Without colonizing interventions, e.g. the clearing of woods, the selection of species to be grown, the ploughing of the soil, the breeding of favorable races of animals etc., this leap in socio-economic

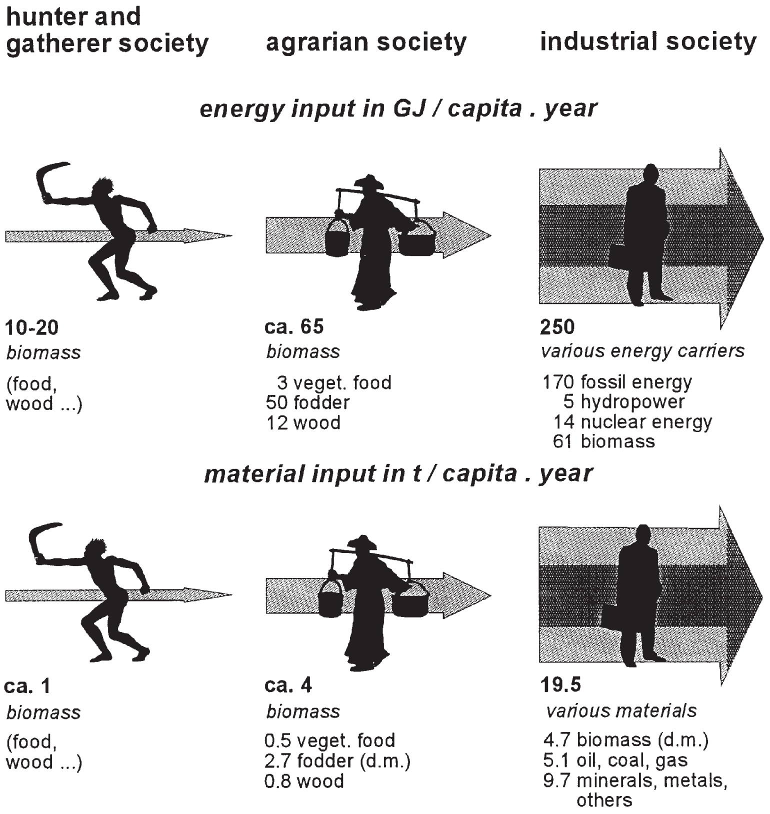

FIGURE 1. Characteristic metabolic profiles for different social formations. *Sources: hunter and gatherers: own estimates based on Harris (1991), agrarian society: Törbel 1875 (Netting 1981), industrial society: average of Austria, Japan, Germany, The Netherlands, and the USA.*

material and energy consumption would have been neither possible nor required.

It would not have been possible, because in unmanaged ecosystems a comparable concentration of edible plant biomass and density of animals to be hunted would never have existed. And it would not have been required, since hunters and gatherers don't have to grow the food for their game. Under agrarian conditions the population density rises roughly by a factor of 10. At the same time, the per-capita energy extraction from the environment is about four times higher than before. Nevertheless these societies manage to maintain this tremendously increased total energy input while keeping their environment inhabitable – at least for some hundred or thousand years.

What, then, is the price? On the part of society, the main price seems to be increased labour. Labour does not only have to be invested in metabolic activities (such as picking plants or hunting), but beyond into colonizing activities: Ploughing, regulating rivers, building fences, weeding, feeding, constructing stables etc. In a hunter and gatherer society, an increase in labour, in the longer run, does not increase returns. It rather depletes the environment more effectively, and thereby exacts more frequent or farther raids that soon prove to be self-defeating. So hunter and gathering societies tend to have a cultural preference for idleness (Sahlins 1972). Just the opposite holds for agrarian societies: With a mode of production based on colonizing the environment, an increase in the amount of labour does indeed improve returns. Thus they tend to be organized in a way which secures the continuous application of a lot of labour: by religious beliefs, for example, that honour hard work, by hierarchies and enforceable property rules that protect the fruit of this labour. We believe that many common attributes of agrarian societies can be better understood by the functional neccessity to sustain a high amount of colonizing labour than by technological development, as is usually argued in the Marxist tradition.

On the part of the environment, there is a price to be paid, too. As societies try to 'optimize' natural systems according to their preferences, profound changes occur. Some of them may be intended, others may be side-effects. These changes may affect ecosystems, organisms, or even the genome. For example, by regularly ploughing the soil, agriculture keeps natural ecosystems in an early successional stage and thus excludes woody species. Additionally, by sowing, the farmer defines which species should grow. Nearly all relevant system parameters (energy flow, food chains, species composition and diversity etc.) are affected by these and all other colonizing interventions. Note that these changes may be valued positively or negatively, depending on the point of view. Thus it appears to be useless to ask if colonization *per se* is 'good' or 'bad' for the environment.

As an example, we will focus on one aspect of colonization related to biomass utilization by agriculture and forestry. As the amount of societal biomass utilization reaches higher proportions of the naturally available biomass, there is a strong selection in favor of animals and plants that humans need (and some others less popular among humans, such as mice and rats). Patterns of competition and hence selection criteria for wildliving species are altered and many species become extinct.[7] Even worse, if a territory is exploited beyond its carrying capacity, it may experience irreversible degradation. Thus agricultural colonization serves the purpose of optimizing the use of solar energy available in a readily usable form, i.e. biomass – but it is contained within certain limits given by the size of the territory, its soil and climate.

For an appraisal of the ecological limits to biomass utilization, the notion of 'net primary production' (NPP) is of outstanding significance. The NPP is the amount of solar energy that green plants can annually incorporate as biomass. It is the nutritional base of all heterotrophic life. Humans live on it as well as all animals and all microorganisms that are not capable of photosynthesis. The amount of NPP of green plants depends mainly on climate (temperature, water availability) and soil quality. On a planetary scale NPP can only be marginally increased by human techniques. More easily it can be (and actually is) reduced through overuse of land and subsequent degradation. While it is technically feasibly to increase the NPP of cultivated land compared to the previously existing natural ecosystems (above all by irrigation in dry regions), many anthropogenic biotopes, such as cornfields or orchards, are less productive than the natural ones that would prevail in the same region, such as natural forests. Thus agriculture, forestry, and construction contribute to an 'appropriation' of net primary production for societal needs in two ways: (1) by reducing the amount of NPP produced by green plants (by preventing the growth altogether by constructing buildings or roads or by reducing the productivity of ecosystems, e.g. by clearing forests and replacing them with less productive agricultural systems as for example meadows) and (2) by harvesting biomass and using it for social needs – be it food for humans, fodder for livestock, or wood as fuel, construction material etc.

The proportion of NPP appropriated by society, therefore, is a good indicator of the scale of the societal metabolism *vis-à-vis* its natural environment. If a society appropriates more than 100% of the NPP, it consumes more than what is growing and very quickly depletes its one and only nutritional base. Practically, the 100% limit is much beyond what can be exploited sustainably, because this would mean that there would not be any nutritional energy left for all other wildliving heterotrophic organisms – animals, microorganisms and fungi. While we have no clear indication as to which proportion of NPP may be sustainably appropriated, there are good reasons to suspect that excessive NPP appropriation results in species loss. Thus there must be some limit to the proportion of NPP appropriation well below 100%.

For agricultural societies, which depend nearly exclusively on energy originating from biomass, limits to NPP appropriation constitute an absolute boundary, however inventive and

Waste products of industrial civilization, 1981. L. Psihoyos/Matrix/Cosmos

efficient their technologies may be (Smil 1991).[8] Thus the energetic metabolism of agricultural societies cannot exceed a certain point.

The enormous increase in the scale of metabolism in the process of the industrial revolution was only possible by a shift from biomass to fossil fuels, i.e. coal, oil, and natural gas. Towards fossil biomass industrial society behaves like previously hunters and gatherers: it just exploits it without caring for its reproduction. This does not, however, imply that the biomass use of industrial societies is lower than that of agricultural societies. Even for industrial societies, NPP remains an important boundary, since it remains their sole source of nutritional energy for humans and livestock. To some extent, these boundaries are extended because agricultural yields per unit area can be significantly raised by ‘fossil fuel subsidies’ (tractors, fertilizers, pesticides).

This does not, however, reduce NPP appropriation. According to Vitousek et al. (1986), contemporary human societies appropriate about one third of the global terrestrial NPP and – as a result of population growth alone – this percentage may be expected to double within the next 35 years (Meadows et al. 1992). According to Haberl’s (1997) calculations, the Austrian society appropriates 41% of the aboveground NPP on its territory. The overall energy consumption (biomass, fossil sources, and hydropower) exceeds the hypothetical NPP of the natural vegetation prevailing in the absence of human interference on Austrian territory by more than 10%.

If one single species (together with its domesticated animals) needs half of the nutritional base of all animal species together, it can be expected to compete the rest to extinction. For example, as Smil (1991) has estimated, humans and livestock account for 96% of the total global biomass of terrestrial vertebrates – indeed a stunning proportion. A similar argument may be applied to the relation between the industrialized countries of the North and the – mainly agrarian and industrializing – countries of the South. By their excessive metabolism the industrialized countries just do not leave enough environmental space (be it in terms of raw materials or natural absorption capacity for emissions) for the South to develop along the same paths.

5. How can industrial societies perceive their sustainability problems and respond to them?

In the previous sections we have tried to show that the current problems of global environmental change are consequences of the quantity and quality of the metabolism of industrial societies, and of the quantity and quality of colonizing interventions into natural systems necessary to secure the required resources. The main conclusion which follows from this argument is that a policy towards sustainable development of industrial societies should focus on strategies to reduce material and energy turnover. This would imply a concentration of efforts on a strategic level instead of traditional sectoral approaches of environmental policy. We believe that this is a necessary prerequisite to tackle the driving forces behind global environmental problems.

Such strategic efforts for sustainable development require substantial changes of existing structures and dynamics. Thus they can only be implemented if there is a broad consensus on their necessity and suitability. It is a key question, therefore, how industrial society may perceive its sustainability problems. Although many people may be convinced that climate change actually is a problem, that the destruction of the ozone layer is real, and that biodiversity is being destroyed, fundamental changes of current policies still remain an intellectual exercise in obvious contradiction to most of industrial society's everyday experience.

Hunter and gathering societies could experience that they hunted or harvested too much or too effectively. If this was the case, they then had to wander about ever more to find appropriate nutrition. They could realize that there were too many mouths to be fed for a given environment, and culturally downsize their procreation. Similarly with agrarian societies: They were able to learn from the consequences when they exploited the soil too much, or had too many animals to feed on, and accordingly improve their balance. With respect to procreation, however, there was a double-bind: Child labour improved their conditions of living, and having children increased survival rates in old age. On the other hand, an increasing number of mouths could not be fed. There was a dilemma that could not be resolved by most agrarian societies in a sustainable way (Netting 1981).

But what do industrial societies experience? Their experience tells them that raw materials are becoming cheaper, agriculture is producing an excess of goods that cannot be sold on regular markets for regular prices, their population lives ever longer, maybe even healthier and more comfortably. They do not depend on their territories but, on the contrary, gain a lot by far-reaching exchange and transport; they better keep their growing labour forces busy most of the time, although it may be hard to procure a sufficient amount of work; they can mitigate their internal social tensions by economic growth and, finally, most parts of the world strive to imitate their mode of production and living. Why, then, should they believe in intellectual, scientific insights rather than in their reinforcing day-to-day experience?

The problem, therefore, of taking a turn towards a more sustainable mode of production and living is to create conditions that provide society with different experience – with kinds of experience that make the right alarms ring.

In figure 2 we take a systemic look at the type of problem industrial societies face, if development towards sustainability means scaling down metabolism. The system is modelled as a positive feedback-loop between three quantities: 'quality of life', 'prosperity' and 'metabolism'. The problem consists in delinking 'metabolism' both from 'prosperity' and from 'quality of life'. This bears some similarity to the way Meadows et al. (1972) put the problem: There it was argued that continued economic growth ('prosperity') invariably meant environmental degradation and, therefore, should come to a halt. On the other hand it was argued that you could delink improvements in the quality

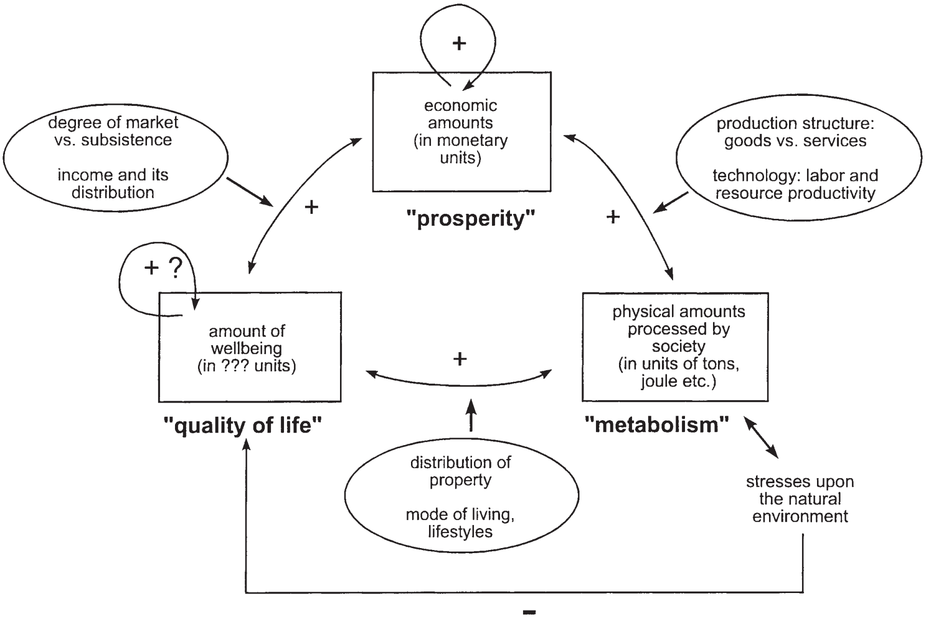

FIGURE 2. A systems model for the interrelations of monetary, physical and wellbeing dimensions.

of life from economic growth, or that further economic growth was not needed to improve quality of life. This 'zero growth formula' met harsh political rejection. We explicitly triangulate the argument: It is not economic growth that puts a pressure upon the natural environment, but it is the growth in physical amounts of energy and materials a society processes.

Economic growth typically leads to a growth in physical terms, but this does not neccessarily have to be so. Even under given circumstances the two dimensions do not grow proportionally (Adriaanse et al. 1997, Fischer-Kowalski et al. 1997). On the other hand, does an increase in wellbeing presuppose an increase in material and energy consumption? In a bottom range it obviously does: As long as there is not enough food, warmth and shelter, the quality of life can only improve if the neccessary material preconditions are provided for. But beyond this it may well be a matter of culture how many material goods are required for wellbeing.

Let us now look at the factors mediating between the nodes of the triangle in figure 2. We presuppose an economic growth mechanism to be at the very core of industrial market economies. It does not really matter for this purpose, whether this be viewed as the 'procreative' force of industrial capital (as Meadows et al. [1972, 1992] assume), as an inevitable byproduct of market competition in conjunction with interest, or as a continuous defense of capitalist profits as in the Marxist tradition. The degree to which this mechanism also drives physical growth depends on production structure and technology. The more an economy provides for 'services' instead of 'goods', the less direct the growth impulse will be. And if the resource efficiency of technology – in the sense of providing for a certain commodity or service with the least amount of material and energetic waste – is improved more quickly than the economy grows, material and energy throughput can even decrease. This, at least, is the hope invested into an 'efficiency revolution' (e.g. Schmidt-Bleek 1994, Weizsäcker et al. 1995, Meadows et al. 1992).

As examples show, there is quite a margin for the raise of efficiency. This has been particularly well studied for the use of energy: Many studies arrive at technical saving potentials well above 50% of current consumption, indicating that the same services could be procured using only half of the current amount of energy (Krause et al. 1993). But the realization of such potentials is among others a matter of relative prices. During the last decades the international division of labour steadily cheapened raw materials, while, at the same time, it raised the price of industrial labour. Therefore, the priority has been to curb expenditures on labour, instead of developing more efficient forms of utilizing natural resources. But particularly in Europe it is not only the costs created by markets, but also a relevant margin of 'political costs' that increases gross wages by about 50% (taxes, social insurance etc.). This is exactly what a 'social-ecological tax reform' as now considered by several European countries is trying to tackle. Social-ecological tax reform implies a gradual shift from taxing wages to taxing energy or resources. If one pursues this course of action, labour intensive commodities and services will become cheaper, whereas energy-intensive commodities will become more expensive. Such a shift in relative prices may be expected to promote technologies which economize on natural resources. According to various studies pursuing this course of action would not curb economic growth, but reduce unemployment, energy consumption, and CO_2 emissions (Krause et al. 1993).

Still the possible effects of an 'efficiency revolution' induced by a shift in prices should not be overestimated. In no way can we see a material and/or energetic reduction by Schmidt-Bleek's (1994) 'factor 10' or Meadows et al.'s (1992) 'factor 8' to be achieved by such means. As we showed above, the overall per capita energy consumption (including food) of a farming village in the last century was just by a factor of 5 smaller than that of contemporary Austria.

But let us now look at the axis between 'quality of life' and 'metabolism'. These quantities are mediated by modes of living, by culturally defined models of a 'good life', and, maybe less obviously, by the modes of social distribution of goods and property.[9] With a predominantly secular and individualistic culture that leaves the regulation of life styles to markets there seems to be little political margin of influencing changes towards a more sustainable development. Since an 'automatism' towards 'postmaterial values' cannot be expected (Dunlap and Mertig 1994), various mediating processes have to be looked upon more closely. In the following we will select some of the less obvious ones for illustrative purposes.

Vegetarianism: A change towards a more vegetarian diet, maybe brought about by sheer health arguments, could reduce societal metabolism by 10 to 20% and would also be a very potent strategy in reducing metabolism in terms of energy.

Reduction of regular working hours: Reducing the 'regular number of hours worked' promises to be a measure with similar far-reaching effects for the mode of living, as a socio-ecological tax reform might be for ecological efficiency. In most industrial countries it is only the minority of predominantly middle-aged males that works 'normal hours' (European Centre, 1993). It is this group of employees, however, that staffs highly influential positions when it comes to determine the standards of 'normality' of ways of living. Their cultural position is causally related to the high and increasing degree of energy and resource consumption. Whoever works that hard claims the right to indulge in luxury and comfort, is eager to avoid the chores of everyday life and usually does not have enough time to provide for his well-being in any other ways than those provided by material commodities. If this dominant model of allocating time declined, many material compensations sought might become redundant; eventually, they might be substituted by services which are more effective to achieve the satisfaction of needs and wants. It is rarely effective to buy a new skirt if one is lovesick, to bet one's luck on a sportscar for fear of being impotent, or to substitute lack of affection by lavishing ever newer toys on children.

Moreover, it may be reasonable to assume that a substantial part of excessive consumption of materials is caused by the fact that consumers are short of time. This involves the whole range of gadgets from hiring taxis to ready-made meals, from energy used for driers to countless decisions in favour of replacement instead of repair. It would be a rewarding objective of research and social experimentation to explore the room for manoeuvre available in this respect. For example, a strategy that seems worth exploring is to compensate for productivity increases by means of time rather than with money. With an average productivity increase of some 2% per year this would imply an annual reduction of four working days. There would be a degressive effect on the income structure: one can hardly offer eight extra days to a manager and one to a secretary. Of course, productivity gains are not distributed equally across the economy – but this problem is being resolved with wage-increases as well. Historically speaking, it is interesting to note that the lower class culture of 'hard labour' that was established in the agricultural era – where it was quite neccessary considering ecological conditions – has been generalized for all classes in industrial society where this patently is ecological nonsense.

Cultural variety: There must be room for social and cultural experience of different ways of life. The gradual dissolution of traditional family structures and regional communities, migration movements, the omnipresence of markets, bureaucracies and the media, and the lack of affection and social recognition, including the deficiency in 'positional goods' associated with that – are phenomena which frustrate an ever-increasing number of people in their endeavour to gain recognition within their social environment. As a result, more and more efforts are spent to achieve this by means of spectacular expenditure of energy as well as of resources, or by means of intimidation and violence. Thus policies that permit and support different modes of living also support a kind of cultural 'biodiversity' generating the chance for changes.

Finally it seems that the predominant *distribution model* in industrial societies, i.e. a fairly steep gradient in the amount of goods and property controlled, but an egalitarian 'equal chances' ideology at the same time, fosters the continuous striving to achieve at least as much as the ones just above oneself and provides a powerful growth mechanism. Thus a more equal income distribution, or maybe just a further loosening of the correlation between various hierarchical dimensions (income, education, age etc.), would help to reduce pressure towards the acquisition of material goods.

We don't feel able to even estimate the reduction potential for societal metabolism inherent in changes of the mode of living. It seems quite obvious though, that the material and energetic efficiency in the production of human wellbeing could be greatly improved – for the sake of a more sustainable development.

Notes

* We are indebted to Mart Stewart, Western Washington University, Bellingham, for his comments on an earlier version.

1. In order to be able to define material flows from the environment into the social system and back to the environment, system boundaries have to be properly specified. It causes remarkable empirical differences if this is not done in an unambiguous way. We suggest to define as physical stocks of a society its human population, its durable artefacts (such as buildings, infrastructure and machines) and its animal livestock. Every material flow used to produce and reproduce this stock, then, is part of society's metabolism (see Fischer-Kowalski et al. 1997 for greater detail).

2. A historical example is represented in Wittfogel's (1955) famous analysis of the relationship between the need to organize and maintain large irrigation systems and the origins of elaborate hierarchical differentiation in early empires.

3. One of the more recent developments is the expansion of 'aquaculture' in fishing.

4. Owing to editorial restrictions we refrain from including broad descriptions of methods, data sources, and many of the references. Research papers with a more exhaustive framing are available from the authors on request.

5. As the Wuppertal Institute and the World Resources Institute show (Bringezu and Schütz 1996, Schmidt-Bleek 1994, 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, 23).

6. Estimates for hunters and gatherers were based on the anthropological literature (eg. Harris 1990).

7. It is true, however, that some forms of colonization, e.g. some less intensive agricultural practices, may also create new habitat types and thus contribute to a more finely structured environment which is able to support higher levels of biodiversity than the formerly prevailing landscape.

8. Windmills, sails and hydropower constitute an indirect source of solar energy beyond NPP, of course, but quantitatively are not that important in agricultural societies (Smil 1991).

9. In contemporary industrial society, 'property' is the most important relation linking (individual) wellbeing to physical goods. Changes in the rules regulating property will therefore invariably have repercussions on the level of metabolism.

References

Adriaanse, A., S. Bringezu, A. Hammond, Y. Moriguchi, E. Rodenburg, D. Rogich and H. Schütz 1997. *Resource Flows: The Material Basis of Industrial Economics*. World Resources Institute: Washington DC.

Ayres, R.U. and A.V. Kneese. 1969. 'Production, Consumption and Externalities', *American Economic Review* 59(3): 282–297.

Ayres, R.U. and U.E. Simonis (eds.) 1994. *Industrial Metabolism: Restructuring for Sustainable Development.* United Nations University Press: Tokyo.

Boulding, K.E. 1973. 'The Economics of the Coming Spaceship Earth.' In: *Toward a Steady State Economy*, Daly, H. (ed.). Freeman: San Francisco, 3–14.

Boyden, S. 1992. *Biohistory: the interplay between human society and the biosphere – past and present.* Man and the Biosphere Series 8, UNESCO and Parthenon Publishing: Paris and New Jersey.

Bringezu, S., M. Fischer-Kowalski, R. Kleijn and V. Palm 1997. *Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability.* Wuppertal Institute of Climate, Energy and the Environment Special Paper 4: Wuppertal.

Bringezu, S. and H. Schütz 1996. 'Analyse des Stoffverbrauchs der deutschen Wirtschaft.' In: *Neue Ansätze in der Umweltökonomie*, J. Köhn and M.J. Welfens (eds.). Marburg: Metropolis, 229–251.

Dunlap, R.E. and A.G. Mertig 1994. *Global Environmental Concern: A Challenge to the Post-Materialism-thesis.* Paper to the ISA's XIII World Congress of Sociology: Bielefeld.

European Centre 1993. *Welfare in a Civil Society.* Report for the Conference of European Ministers of Social Affairs: Vienna.

Fischer-Kowalski, M., H. Haberl, W. Hüttler, H. Payer, H. Schandl, V. Winiwarter and H. Zangerl-Weisz 1997. *Stoffwechsel der Gesellschaft und Kolonisierung von Natur, Ein Versuch in sozialer Ökologie.* Gordon and Breach Fakultas: Amsterdam.

Haberl, H. 1997. 'Human Appropriation of Net Primary Production as An Environmental Indicator: Implications for Sustainable Development.' *Ambio* 26(3), 143–146.

Harris, M. 1990. *Cultural Anthropology.* Harper and Collins: New York (3rd Edition).

Hüttler, W., H. Payer and H. Schandl 1996: *Materialfluß Österreich 1990*. IFF-Social Ecology Paper 44: Vienna.

Krause, F., E. Haites, R. Howarth and C. Koomey 1993. *Cutting Carbon Emissions: Burden or Benefit? The Economics of Energy Tax and Non-Price Policies.* International Project on Sustainable Energy Paths: El Cerrito, California.

Meadows, D.H., D.L. Meadows, J. Randers and W.W. Behrens 1972. *The Limits to Growth.* Universe Books: New York.

Meadows, D.H., D.L. Meadows and J. Randers 1992. *Beyond the Limits.* Chelsea Green Press: Post Mills.

Metha, L. and V. Winiwarter 1997. *Stoffwechsel in einem indischen Dorf: Fallstudie Merkar.* IFF-Social Ecology Paper 49: Vienna.

NETTING, R.M. 1981. *Balancing on an Alp.* Cambridge University Press: Cambridge.

REDCLIFT, M.R. 1993. 'Development and the Environment: Managing the Contradictions.' *Innovation in Social Science Research* 6(4): 443–456.

SAHLINS, M. 1972. *Stone Age Economics.* Aldine de Gruyter: New York.

SCHMIDT-BLEEK, F. 1994. *Wieviel Umwelt braucht der Mensch?* Birkhäuser: Basel.

SIEFERLE, R.P. AND U. MÜLLER-HEROLD 1996. 'Überfluß und Überleben. Risiko, Ruin und Luxus in einfachen Gesellschaften', *Gaia* 3(3–4), 135–143.

SIEFERLE, R.P. 1982. *Der unterirdische Wald. Energiekrise und industrielle Revolution.* Beck: Munich.

SMIL, V. 1991. *General Energetics: Energy in the Biosphere and Civilization.* Wiley: New York.

VASEY, D.E. 1992. *An Ecological History of Agriculture 10.000 B.C.–A.D.10.000.* Iowa State University Press: Ames.

VESTER, F. 1976. *Urban Cities in Crisis.* Deutsche Verlags-Anstalt: Stuttgart.

VITOUSEK, P.M., P.R. EHRLICH, A.H. EHRLICH AND P.A. MATSON 1986. 'Human Appropriation of the Products of Photosynthesis.' *BioScience* 36(6), 368–373.

WEIZSÄCKER, E.U., A.B. LOVINS AND L.H. LOVINS 1995. *Faktor 4: Doppelter Wohlstand, halbierter Naturverbrauch.* Droemer Knaur: München.

WITTFOGEL, K.A. 1955. 'Developmental Aspects of Hydraulic Societies.' In: *Irrigation Civilizations: A Comparative Study,* J.H. Steward (ed.). Pan American Union, Social Science Monographs I: Washington DC.