Social Ecology

Social Ecology Working Paper 32

Metabolism and Colonisation
Modes of Production and the Physical Exchange between Societies and Nature

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Wien, 1993

ISSN 1726-3816
iff Social Ecology | Schottenfeldgasse 29 | A-1070 Vienna | www.iff.ac.at/socec/

Metabolism and Colonization. Modes of Production and the Physical Exchange between Societies and Nature.

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1. Introduction

Well a decade ago Catton & Dunlap (1978) suggested it would require a new paradigm within sociology to successfully deal with the relationship society-nature. They accused the social sciences and sociology in particular to follow a "human exceptionalism paradigm" (HEP) that would not allow human beings and society to be viewed as "one among other" forms of life on this planet, as part of the "web of nature". They outlined some general features of what they called the "new environmental paradigm" (NEP) required for a fundamentally different approach. Such a paradigmatic change has not taken place, as far as we can see (Dunlap & Mertig 1991; Devall 1991). And we can well understand how highly uncomfortable such a paradigmatic change for sociology would be: as uncomfortable (if not irreconcilable) as a "no growth"-perspective is for modern economics.

The vantage point for a paradigmatic change is a preconception that there is something going wrong in the society-nature-relationship, that society behaves in a way that destroys the natural basis it rests upon. There is no agreement though, how radical this "wrongness" ought to be conceived: whether it is a matter of minor amendments or of imminent danger to survival, whether it is something that will more or less regulate itself or will require massive intervention or cannot be regulated by society at all anyway - all these conceptions exist, among sociologists as among other people, and there seems to be no professional consensus among sociologists about the means and ways to approach truth.

Main stream sociology tends to view society as a system of communication (see Luhmann 1986), and disregards its material respectively its physical properties. Similarly neo-classical economics: The economy is regarded as a system of stocks and flows of money, and it is only the monetary side of reality that is addressed by economic theory. At their best physical concepts are discussed as tools for the development of monetarization[2].

These kinds of theories are not very helpful in conceptualizing the relationships between societies and their natural environments. For such a purpose societies must be looked upon as forms of organization that are supposed to serve one ultimate purpose: sustaining the species mankind. These forms of organization vary considerably by time and space, as is well known, but in all cases they have to provide for the basics of nutrition and biological reproduction under specific environmental circumstances. It is not self-evident that they are able to do so; many societies are known to have collapsed or even died out because they could not.

Providing sufficient nutrition, housing and material welfare, societies have evolved by organizing a continuous energy and materials flow from their natural environments, transform them in various ways useful for human life and discharge them again into natural environments. According to physics the energy and materials intake will equal the amount of output, only the quality will have changed: in terms of thermodynamics entropy will have increased, thereby providing the differentials biological and social life depends upon. We suggest to include these physical processes into the conception of society. This permits to regard societies from a physical perspective: as systems of material stocks and flows, regulated by biological as well as cultural, technological and economic processes. These systems are sustained in specific environments. If the environment changes (possibly as a consequence of the system's behavior, or for endogenous reasons such as meteorites or the like), the system will change. In contrast to ecosystems these changes do not occur by biological evolution, but by something we choose to call "cultural evolution" (Harris 1991, pp.25). Cultural evolution does not depend upon changes in the composition of genetic information (all humans are, whatever their social organization may be, genetically very much alike, and their genetic outfit has practically not been altered since the advent of homo sapiens sapiens), but on the composition of culturally available information incorporated in human brains[3] and social organizations.

2. The question for sociology: How does society regulate its exchange processes with its natural environment?

Societies may just as ecosystems be characterized by their energy density. Energy density means the amount of energy taken in and being transformed by the system per calculation unit (space or organism). The minimal energy density of societies is determined biologically by the metabolism of its member organisms. Since humans are pretty big mammals, they require a fairly high energy flow (not per kilogram mass, in this respect mice for example have a higher turnover than humans, but per organism), even at a minimum level of reproduction[4]. The energy density of contemporary industrial societies of course is a multiple of this.

Ecosystems with a high energy density seem to follow one of two alternative patterns:

(1) *"Closed cycle systems"* have fast and rather closed cycles for all important nutrients. They manage to gain control over most environmental conditions necessary for their existence. An example for this pattern are tropical rainforests. They are able to continuously recycle their own nutrients. They can practically go on forever as long as none of their highly interdependent parts are destroyed by external forces (such as men chopping thousands of trees). They create and reproduce the environment they need: Their micro-atmospere, their water circulation and their mineral cycles. Of course they depend on external ("environmental") circumstances such as the intensity of sunshine and the macro-climate. But these circumstances are independent of the system. Thus the "carrying capacity" of the environment for such systems is basically determined by the size of the planet (respectively, in the case of rainforests, by its terrestrial space).

(2) *"Flow systems"*, for example floodplains and updwelling regions in oceans, depend upon an external nutrient supply that they cannot themselves reproduce. They can only exist as long as this nutrient supply is sustained (and the system's offproducts are being removed or can be deposited). Thus, flow systems depend on their environment to remain relatively constant, although they contribute to change it: they extract nutrients from it and discharge outputs to it. Here the notion of "carrying capacity" refers to many processes within the environment determining its ability to regenerate, processes out of the systems reach of control.

So far societies obviously belong to the second type, the "flow type" of systems. Locally several collapses have occurred, but globally that seems to have worked well, if judged by the size of the human population. How could it work?

Strategy one: small is beautiful

One strategy is to remain small in relation to the relevant natural environment. If the system is small enough, the effects its intake and its output have upon the environment remain negligible (see **Figure 1**). "Size" has to be operationalized; it corresponds to energy density, or, to use an organismic term referring to matter rather than to energy, to the dimension of the systems *metabolism*. In the case of societies this metabolism is a function of the size of the population and their mode of production. Minimally it is the sum of the metabolisms of the human organisms that are sustained by a society.

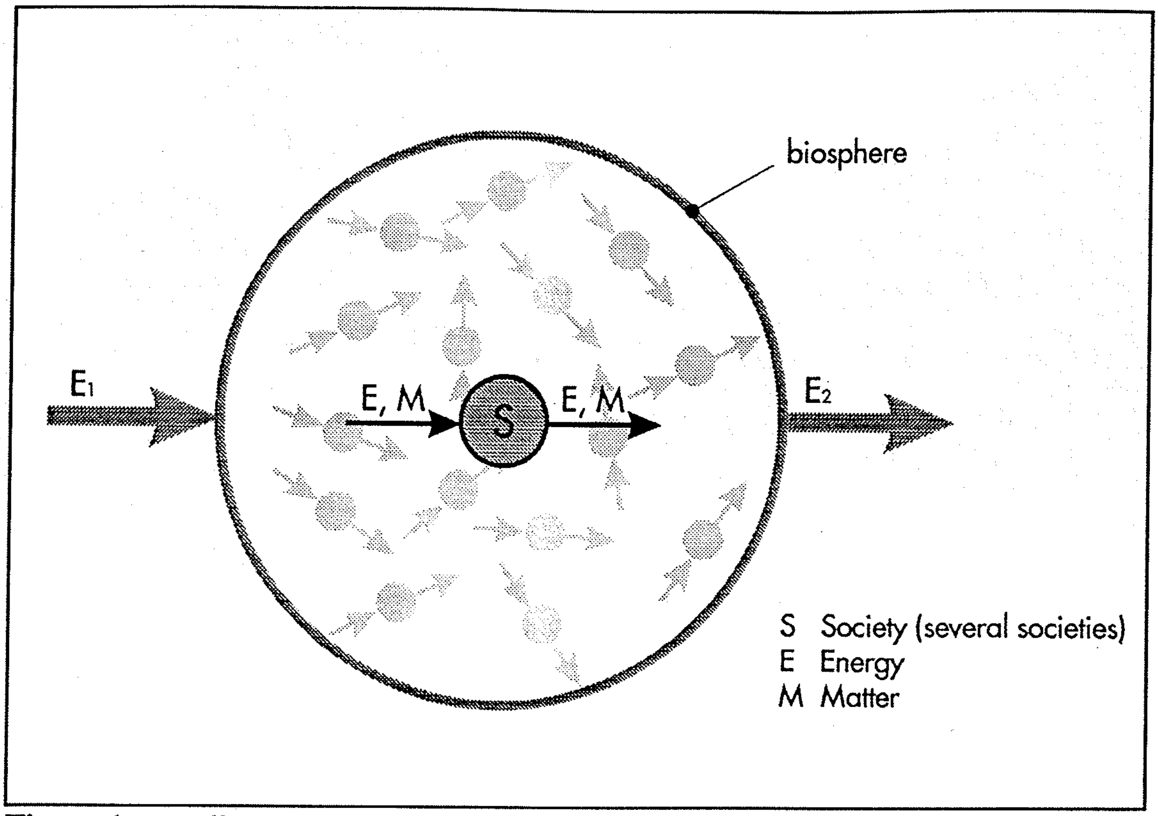

Figure 1: small system's metabolism in large environment: hunter-and-gatherer societies

This strategy was employed by the hunter-and-gatherer societies that make up for most of human history (for a time span of 30 000 years or more). Living in bands of well below 100 members, the prehistoric (and the few contemporary examples surviving) paleolithic societies had a very low population density (even in favorable surroundings less than two persons per square mile, which is much less than one person per square kilometer, see Harris 1990, p.24), and their societies' metabolism basically equalled the sum of the biological metabolisms of their members. As can be judged from anthropological findings (Angel 1975), they were well nourished, and it probably took them relatively few working hours to secure their subsistence (Harris 1991, pp.75, Lee 1969). This was possible because of an almost zero growth of the population. Overall population growth rates for the time 40 000 to 10 000 a.c. are an estimated 0.001% per year. Had they been at the 0.5% rate of later agricultural societies, the world population would have arrived at a stunning $6*10^{23}$ at the end of this period, which would have been 10^{14} times more than it is now (Harris 1990, p.24).

There are many indications that the stability of the size of the population was not due to "natural causes", but was effectively culturally regulated by these societies, mainly by means of (preferrably female) infanticide (Hassan 1973, and extensively Harris 1990, p.26ff)[5].

Nevertheless mankind expanded during this period to an estimated number of 5 million people and spread from its African origins all over the planet, even to reach Australia (as the only placental mammal). And nevertheless human societies depleted their local and regional natural environments to a degree that forced them to change their mode of production. Be it for reasons of climatic change (the end of a glacial period, the Wurm, occurred at about 10 000 a.c.), or be it because of the improved hunting techniques, many large mammals were extinct and hunters had to shift towards what Flannery (1969) termed "Broadspectrum-Hunting". This did not only mean an intensification of effort from the part of the hunters, but also an accellerated exhaustion of the environment.

Strategy two: terrestrial colonization

Middle Eastern societies were the first to develop a new mode of production, based upon the domestication of animals and agriculture. This implies a new mode of intervention into the environment: colonization. This is a type of intervention qualitatively different to the exchange relations we described as "metabolism" above. By their metabolism societies extract materials ("nutrients") from the environment and discharge offproducts ("feces"). These nutrients do or do not regenerate by processes out of the reach of intentional social regulation[6]. By "colonizing" parts of the environment, society intentionally changes some elements of the environment so that it would render more exploitable for social needs. At the same time society intentionally contributes to organizing its regeneration. The most simple form of this is sketched in **Figure 2**, where this regeneration is achieved by leaving colonies out of use for some time period.

Historically and regionally one may find various different examples of creating and treating "colonies". Hack-and-slash methods in tropical rainforests (where the ashes of burnt trees serve as fertilizers), fertilization by animal manure and fallow periods in rainforest agriculture, and flooding systems in irrigation agricultures. But "colonization" does not only refer to space (and the problem of maintaining soil fertility), but also to the domestication and breeding of animals and the cultivation of plants. Colonization seems to be the core invention of the neolithic "revolution", preceding changes in what we we would consider changes in "metabolistic" techniques such as making use of metals for tools. The problem common to all "colonization" is how to maintain the basic self-regenerating quality of colonies despite intensified exploitation, how to organize the investment of human labor and resources into this regeneration process and how to set limits to "exploitation beyond reproduction"[7]. Harris (1990) describes the critical role of the cultural regulation of food-taboos and prescriptions: He analyses that the prohibition of eating pork in the Middle East

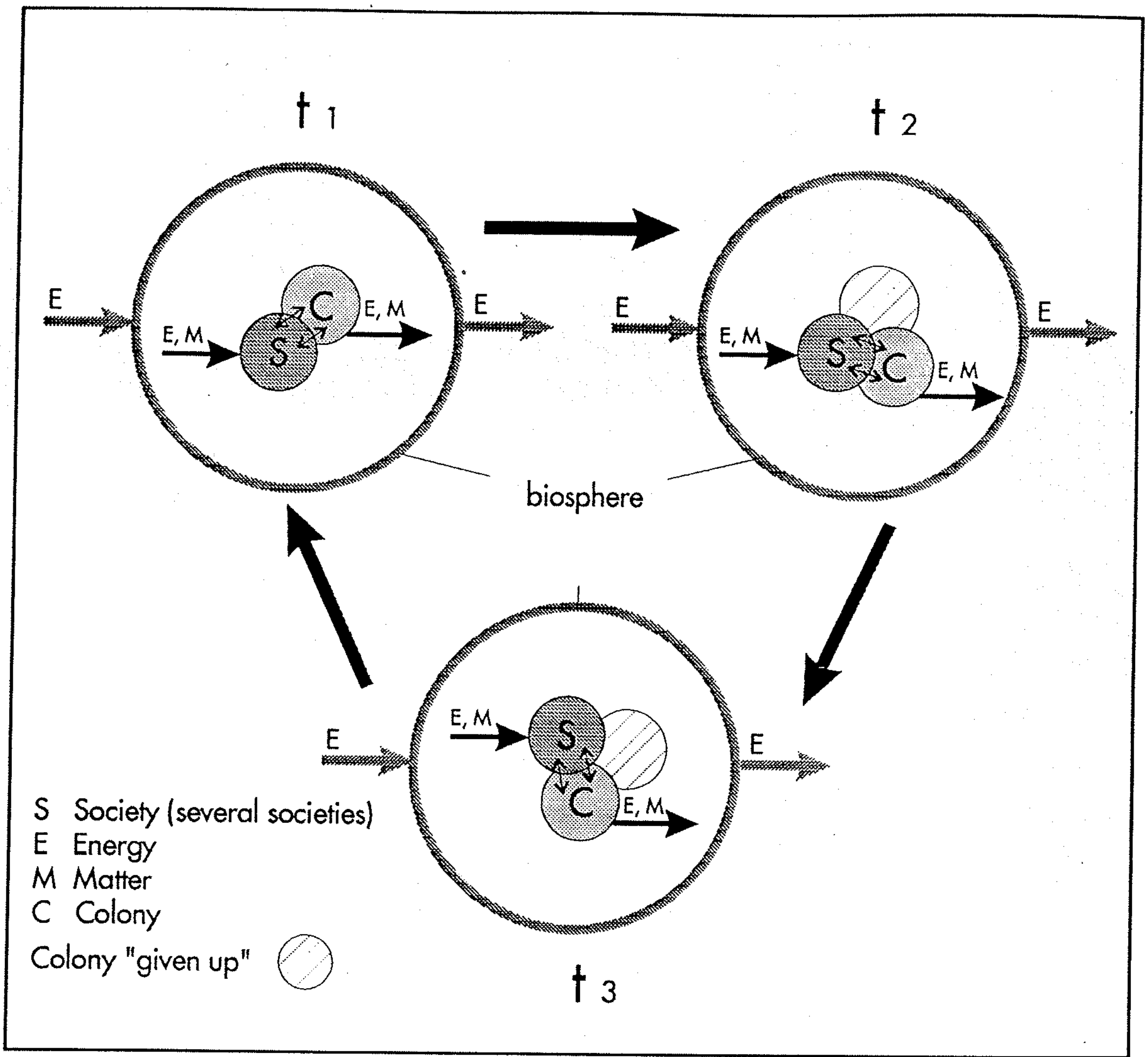

Figure 2: metabolism supported by colonization: agricultural societies

corresponded to pigs becoming direct nutritional competitors of humans as a consequence of deforestation (in the woods before pigs had been able to feed on themselves) in this region. Had there not been established a general religious taboo (Third Book Mose) on pigs, their further breeding would have required those grains (and other increasingly scarce resources like shadow and waterpuddles) needed for the supply of humans. Similarly the cultural creation of the "holy cow" in India (and even more so religiously supported complete vegetarianism) can be explained as a means to protect the environment from depletion, respectively securing the protein supply of humans at costs the environment can bear (Harris 1990, pp.180). Under specific conditions even extensive ritual cannibalism as with the Aztecs may occur and can be interpreted as "environmental protection", supplying protein to humans other than at the expense of the environment (Harris 1990, pp.128).

Colonized environments allow for a much higher population density than their natural predecessors. At the same time they seem to stimulate population growth. Under hunter-and-gatherer conditions the nutrient supply largely depended on the natural reproduction of game and plants; not much could be gained by the intensification of labor. Under agricultural conditions extra labor, particularly child labor, may render returns beyond costs, and so the people tend to have more children - or so at least Harris (1990, pp.95) argues. During the neolithic period the human population increased by 0.1% annually, during the Ancient Empires by 0.5%, rendering a world population above 200 millions by the end of this period (Hassan 1981, quoted from Harris 1991, p.96)[8]. This population increase occurs, although the average nutritional and health status of the people is worse than before.

The innovation of colonization also creates new preconditions for the metabolism of societies. They become sedentary; centralized political powers and centralized infrastructures are established. As a consequence gigantic masses of stone are moved and processed for the construction of buildings, storehouses, fortresses, city walls, dams, roads and the like. Millions of cubic meters of soil are being ploughed and exposed to erosion. Equally human interventions into regional water households increase: irrigation systems are established, the water supply for urban settlements is organised. The technological innovations in metallurgy and shipping cause whole regions like the Mediterranean to be stripped of their woods, with the accompanying climatic changes.

Thus, the invention of agriculture and animal husbandry permitted more people in larger societies to exist, for the price of on the average more miserable living conditions (in terms of nutritional status, workload and social inequality) and intensified interventions into the environment. The metabolism of societies had increased in size and been diversified: Had it before been concentrated on (and more or less confined to) human nutrition, there were now added means of construction, metals and a lot more use of water and wood. As a consequence of this, despite the lower nutritional level (and the scarcity of meat in the average diet), the physical metabolism in terms of mass throughput per person living in the societies under this new mode of production was probably several times the biological minimum.

Nevertheless periodic famines were a constant feature of agrarian societies, and a recurring motive for colonial expansions. The most farreaching and successful expansion was the expansion of the Old World into the New World beginning in the Sixteenth Century. Crosby (1990) attibutes the success of this expansion not so much to the technological superiority of the Europeans in shipping and armament, but to their "ecological sample-bag" inherited from the very beginnings of this civilization in the Middle East. According to him the most important elements of this sample bag that accounted for superiority were domestic animals and microbes. The rich collection of domestic animals (such as goats, sheep, pigs, horses, hens etc.), permitted in combination with the sustained ability to digest milk (which was genetically specific for Europeans) long journeys and far away new settlements without dying from malnutrition, and the collections of microbes breeded in urban settlements and able to quickly decimate or even extinguish the virgin populations the conquerors came in contact with supplied the best of all weapons. Thus the environmental depletion of Europe caused by population pressure and the agrarian mode of production could (at least temporarily) be resolved by huge migration processes, lasting for centuries and resulting in the colonization of an ever increasing amount of land all over the planet.

Parallel to this colonial expansion a new mode of production developed gradually within Europe, for which this expansion and the accompanying improvements in the means of transportation (and increased temptations of trading) were of key importance. We are not going to discuss the reasons for this transition to industrialism here in detail, but we will elaborate on what this means in relation to the environment.

The whole terrestrial sphere of the planet becomes colonialized: national states formally take possession of all land and inland waters (and even of parts of the sea; the antarctic being the only terrestrial exeption so far kept out by international contracts). Large parts of these colonies are colonies only in a formal sense, though: They are not "no-mans-land" any more, but neither are they maintained in a way to preserve their capacity for self-regeneration as was (at least to a limited extent) the case with the tradional agricultural colonies. They are simply treated as unexhaustible "mines of nature" and being exploited. For a long period the strategies of "colonization" in the more specific sense are expanded to ever increasing territories, but do not change in quality.

Strategy three: exploitation / deposition of subterrestrial resources

Major qualitative changes occur with regard to the society's metabolism, though. In the first phase human and animal labor is substituted by machines. In contrast to animals machines do not compete human nutrition by consuming edible biomass, but they require large amounts of subterrestrial resources. In the light of the constant scarcity of life sustaining resources of the agricultural era (the supply of animal power competing with humans for nutrition), this may be looked upon as an environmentally benefactory innovation: no other living system human societies might depend upon is vitally interested in subterrestrial resources like metal ores or fossile fuels. But unfortunately this induces new problems, not at the input, but at the output side of social metabolism. As a consequence the atmospheric dimension of human metabolism grows considerably: Had this metabolism of society before amounted to not much more than the biological minimum (required by human breathing and the breathing of the animals humans kept for their subsistence) plus fire for warming and cooking, now vast amounts of medium and long term deposits of carbon, in combination with other substances, were released into the atmosphere. Short term environmental consequences of this were felt quickly (such as the large scale deforestation of Western Europe, which enforced the use of coal, which in turn caused regional smogs detrimental to agricultural productivity, Bowlus 1988), and long term consequences will be felt for centuries to come.

At the same time industrialisation strongly enhanced society's metabolism of water: water as a source of energy and cooling, water as a means of industrial processing and water supplies for the steadily growing urban settlements - in addition to agricultural uses.

With the advent of the "petrochemical age", due to the affluence of subterrestrial reserves of (ancient) biomass, society's metabolism multiplied once more: quantitatively, as a consequence of mass production and mass consumption of new goods, and qualitatively, by the production and emission of "artificial" substances that enter all natural cycles.

Fairly late in the process of industrialization[9] also changes in the modes of colonization occurred, which led to a sharp increase of biomass productivity per acre: the so-called "green revolution". This innovation consisted in the industrial production of fertilizers and in using petrochemical products for defeating nutritional competitors.

During the transition to the industrial mode of production (historically in Europe, North America and Japan, and contemporarily in most of the rest of the world) the traditional cultural regulations of population growth broke down. However insufficient they had been, what followed them was (and is) a veritable population explosion. Population growth rates through 19th century Europe exceeded 0.7% per year (from 187 millions in 1800 to 410 millions in 1900), despite a population export that resulted in growth rates of 1.8% per year for America (Braudel 1985, p.34). In the early phases of industrial development theories like that of Malthus' let it appear inevitable that most members of industrial societies would have to be kept just at the mimimum level of reproduction, otherweise they would bear more children than the labor market could absorb and soil could feed (Sieferle 1990, pp.90). In later stages the mechanism proved to be different: The industrial mode of living very much changed the cost-benefit relation of having children, i.e. lowered the benefits and increased the costs, so that it became culturally established to have very few children or even no children at all (Heinsohn et al. 1979). This cultural change was effective even before the invention of elegant technologies that permitted non-reproductive coital intercourse. Thus in the centers of industrialism the problem of population growth seems to be under cultural and technological control. Not so at the peripheries; and it is still a matter of shere hope that a "demographic transition" will take place there.

But not only the cultural controls of population growth had broken down, the same had happened to the cultural checks and balances concerning the treatment of "natural colonies". Social arrangements against their "exploitation beyond reproduction" or attention and care for their self-regenerating processes were neglected even for some traditional colonies of agriculture. Other realms of the natural environment wich societies strongly acted upon, such as the atmosphere or water cycles, or the evolution of "wild" species, were not treated with the care even an "exploited colony" receives, but simply used as if they had an infinite capacity of regeneration. To include them into "colonization strategies", that is to treat them in ways agricultural societies had learned to treat arable soil, is exactly what some "environmental policies" now seem to try.

Fancy strategy four: global closed cycle system

Now let's come back to the system's approach from above. One possible solution for an energy intensive flow system if it keeps growing and growing[10] within a limited environment is to become all-encompassing, incorporate its environment. This is equivalent to the creation of a mega social system that culturally, economically and technically manages and controls the former "natural environment" as a part of itself, or at least as a "colony" that it exploits but cares for to regenerate (**Figure 3**). This of course means the transformation into a closed cycle system as described above, able to create and to reproduce its own nutrients.

All possible damages inflicted upon the "natural colonies" would have to be treated as damages within society. All of nature would be "posessed" by specific social subjects for specific purposes (not neccessarily for profit purposes though), and damages caused by one subject would be damages to someone elses posessions to be persecuted within social rules. All "natural resources" would be represented within the economy as (not neccessarily private) capital stocks. The mega social system would have to establish all mechanisms for distribution and exchange, and not only on a contemporary, but also on an intertemporal (between generations) basis. This would mean the full mastery over nature, the perfection of the project of the Enlightenment.

Even if this vision were technically feasible (which environmental economists, for example Immler 1989, and technicians tend to assume, whilst biologists tend to deny), it would be a huge social task. For the time being the (fully developed) industrial mode of production feeds about 20% of the planet's human population properly, and its side

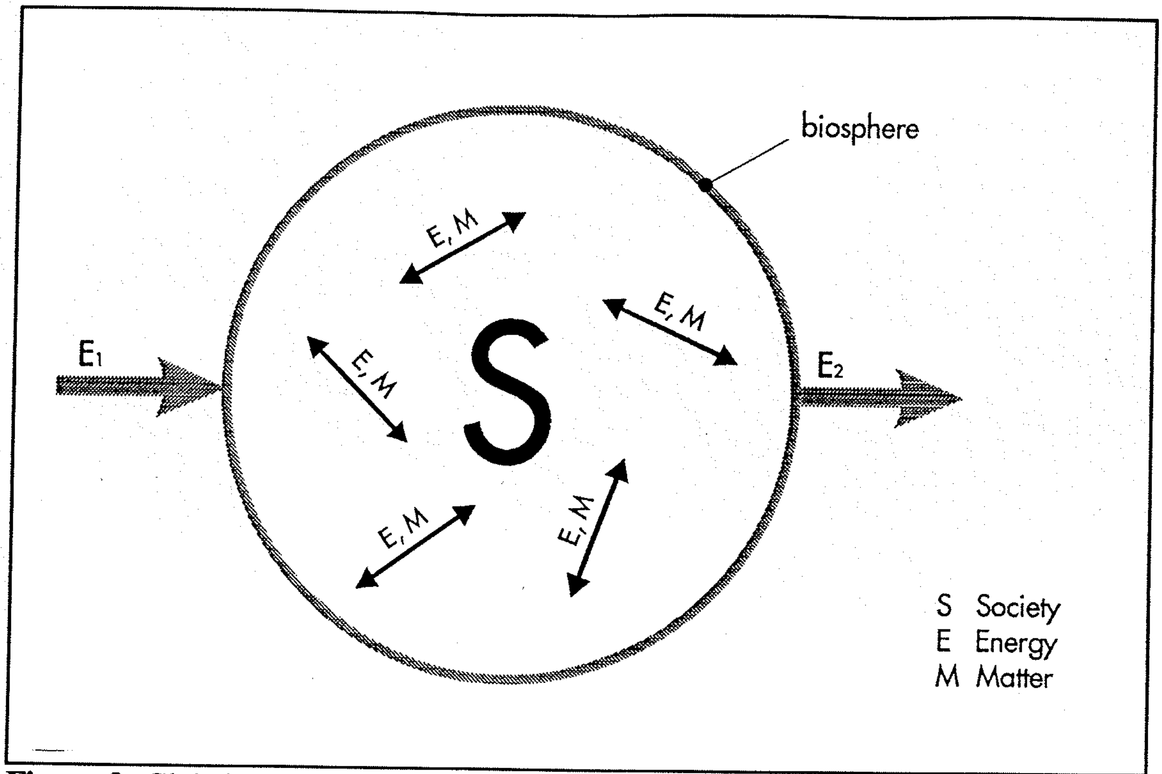

Figure 3: Global control: The whole biosphere as a colony of industrial mega-society

effects keep about 25% starving (UNDP 1992). Mechanisms of exchange and distribution are not solved satisfactorily, not within societies and let alone between societies. And there could not even be reached an agreement that this is on its way to improvement - many would claim the contrary. Can one reasonably entrust the improvement of Nature to the management of the industrial world?

We are very sceptical. So it seems worthwhile to consider another, more modest, basic model of relationships between societies and natural systems, pinpointed in **figure 4.**

Fancy strategy five: multifold conviviality

The story of **figure 4** reads as follows: Let us assume human societies (not *one* unified social system) to share the biosphere with one another and with many other (natural) systems, systems of different qualitative and evolutionary status. Between these systems various exchange relationships exist. They have co-evolved, they are (to a varying degree) interdependent, and they all are to a certain extent self-organized, adaptive and contingent (Nicolis & Prigogine 1987).

Let us use the metaphorics of a neighborhood upon which one depends: In order to survive, and even more in order to get along well, you have to know a lot about your neighbors - much more than just what you might get from them. You will have

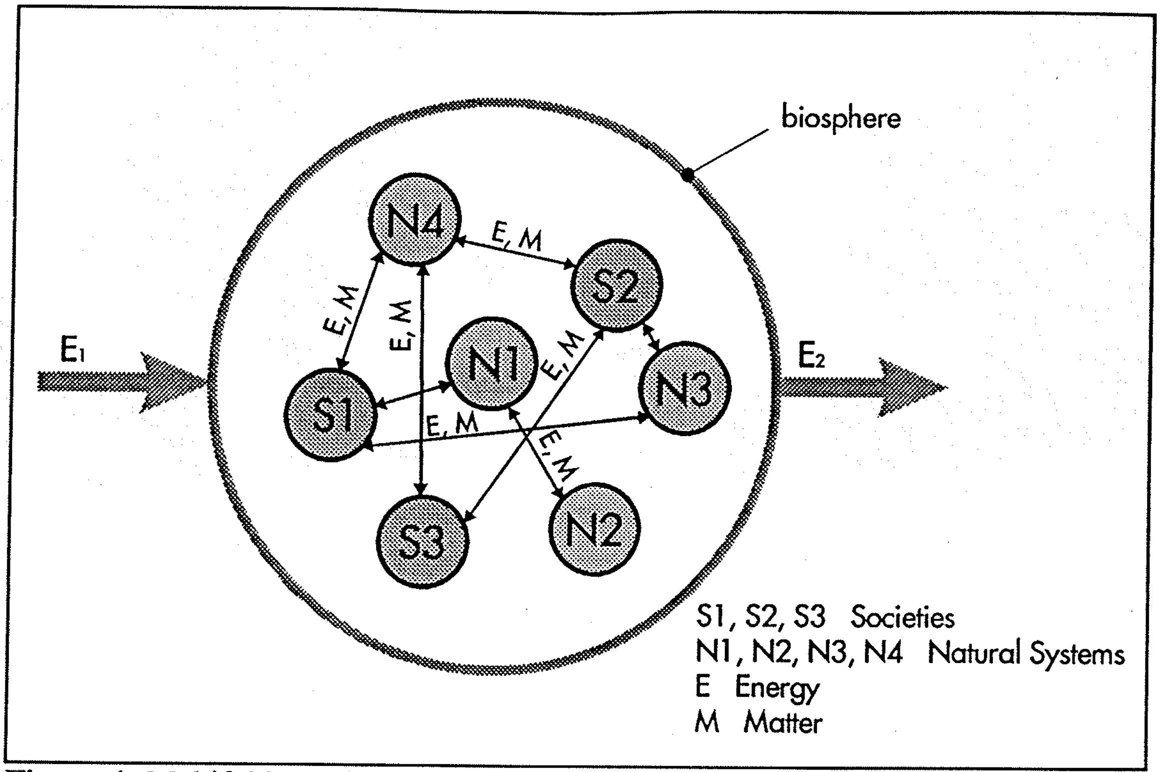

Figure 4: Multifold conviviality

presumptions about their habits, about the language they speak, about their character, you will learn on whom and on what they depend, and you will try out what you must do or not do in order to get from them what you need or to avoid to get from them what you don't like. You might find out you could intimidate and dominate some of them, probably with the help of others, but you'd better not foster the illusion you could control them all. And if you are tempted to such an illusion, remind yourself of your limited knowledge and the contingency of the game. And be careful not to make real enemies, because to fight them will keep you busy all the time and distract your energies from more rewarding enterprises. Be loyal to your allies, but never rely completely upon them. Be aware: if you become a real nuisance for your whole neighborhood, they'll extinguish you. They learn about you as well as you about them. So institutionalize ambassadors to warn against deviation from fair terms of trade, don't load too much responsibility upon your back (so let them live their way if possible) and keep proper records on your neighbors (particularly on your own part in the various deals, since you'll harvest what you've sowed), so you won't be taken by surprise.

Such a "communicative" (or anthropomorphic) view upon the exchanges not only between societies but also between societies and natural systems supposedly appears very strange to natural scientists accustomed to an objectivistic paradigm of nature. It should not appear all that strange to social scientists though. But isn't it shere romanticism? Friendly illusionary utopics? We don't know. The less friendly global control vision does not look very realistic, either. And may be both visions share some common first steps.

So let us take a look at some features of the metabolism and at some parameters for colonization strategies of a contemporary industrial society.

3. The metabolism of an industrial society

Just a few months ago, the debate on sustainable development and possible limits of growth culminated at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro. The variety of conceptions reaches from the "Beyond the Limits" perspective of Meadows et al. (1992) to the "only economic growth can guarantee sustainability" point of view (see for example Schmidheiny / BCSD 1992).

Obviously, if there are limits to socio-economic growth, they are *physical*, not *monetary* limits. The "size" of the social system vis-a-vis its natural environment is determined by the size of its metabolism in physical terms. The most basic physical terms are energy and matter.

Most industrial societies publish calculations of their energy-metabolism, or of what we would consider part of their energy-metabolism: The use of energy-carriers for combustion (in industry, transport and households) and the use of hydroelectric energy, in terms of Joule per year extracted. This does not include the nutritional energy extracted from biomass on which humans live (in competition to other species). Both components of energy metabolism have about the same size, as we will show for Austria further down.

It is absolutely not common for industrial societies to calculate their metabolism in terms of matter, though, that is mass throughput per time unit. In economic input-output statistics a pragmatic consensus has been established over the decades on how to define a national economy's boundary and what monetary flows (and stocks) you have to consider in order to be able to calculate an overall national product. An analogous problem has to be solved if one attempts to calculate the physical flows (and stocks) of a society in a specified period of time. In order to determine what amount of materials (in tons) flows "through" a society per year, or is being stocked "within" a society, you have to be able to tell at what point some material "enters" and at what point it "leaves" society. This is by no means trivial. Do the waters of a river crossing a national border or snow that falls "enter" this society and then "leave" it again? Is the crumb of arable land part of society's material "stock", and if it is, for how many centimeters depth? Many questions of this kind open up.

The most reasonable solution for these problems, so it seemed to us, was to look for the physical counterparts of economic processes. Only matter that is intentionally processed within a society's economy is what counts. At the "environmental origin" of these processes one usually has to deal with some conceptual and even more so operational trouble: How much material is turned over and put aside in mining? How much earth is turned over by ploughs (for a discussion of the problem see Bringezu 1993)? How do you deal with the amount of water stored by dams for hydroelectric purposes? Do you calculate agricultural products including or excluding the water they contain (e.g. grass - hay)?

Steurer (1992) has made a first attempt to handle these problems empirically for the Austrian society and to calculate the material yearly throughput for 1988. He defines the "boundaries" of the Austrian society in a twofold manner:

A) As a boundary between the Austrian and other societies; this conforms to the ordinary definitions of the national state: products of another society that cross the Austrian state border are considered to "enter" the Austrian society as imports (not in monetary units, but in tons). This of course includes many raw materials sold as goods - but it does not include the extra materials that have entered the production process in the country of origin. In the same manner exports "leave" the Austrian society.

B) As a boundary between the Austrian economy and its natural environment. If ground water for example is extracted, used for agricultural, urban or industrial water supply, these amounts count as a throughput, for example. If cattle consumes a certain amount of hay, this counts. If air is used for combustion processes (and the oxygen transformed to CO_2), the mass of the air needed for this purpose counts[11]. If metal ores (together with a lot of other material), petroleum or gas are extracted, they count.

Steurer's calculations are based upon the available variety of economic statistics. Some problems of both a conceptual and an empirical nature would require further research, but the results as presented in **Figure 5** serve well as an overview of the whole structure of a modern industrial society's metabolism.

Austria has 7,8 millions inhabitants. The Austrian society's material throughput per year amounts to almost 4 billions of tons, which is a rate of nearly 500 tons per inhabitant per year, or 1.3 tons per day.

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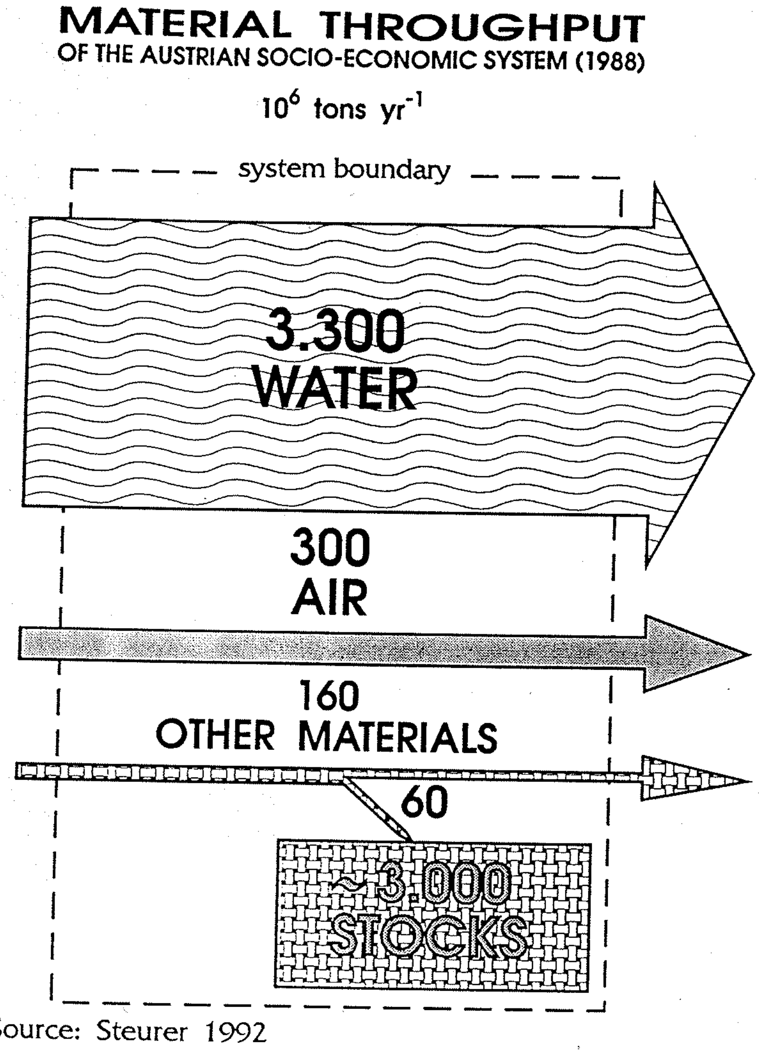

Figure 5: Material throughput of the Austrian Society (1988)

It is amazing to see that the overall structure of an industrial society's metabolism very much resembles that of an ecosystem: The most important throughput is water. Water amounts to 88% of the total metabolism; three quarters of this water are used by industry (mainly for cooling purposes) and for the production of electricity; only 5% are used for irrigation in agriculture and the remaining 20% by households (and small crafts) (see Steurer 1992, p.6). The total throughput of water amounts to 423 tons per inhabitant per year, or 1160 liters per day (as compared to a biological minimum of two liters for drinking, and maybe another 50 liters for cooking and washing).

The next largest segment of the metabolism ist air: 8% of the society's throughput consists of air respectively its oxygen part for combustion and for technical processing[12] (mainly in the production of iron). Per inhabitant this makes for 38 tons/year resp. 105 kg/day. Human (and livestock) respiration is not included, as it reasonably should. An adult human needs about 13 kg of air per day for breething. Another conceptual problem arises with regard to the net oxygen production of forests: in Austria they produce about 20% of the amount of oxygen used by combustion. But the economic purpose of forests so far is not the recycling of air; this is just the way they function naturally. Thus the oxygen production of forests was not included.

Only 4% of material input into society consists of solid stuff; almost one third of this is put on stock (see also **Figure 6**). 75% of solid input materials are extracted from the natural environment within national boundaries; one fourth is being imported, out of which raw materials (mainly: energy carriers, timber and metals) account for three quarters. It seems remarkable that even highly developed industrial societies in terms of mass input live on their "national territories". They make use of local water, local air and even mostly local solid raw materials. The major exception from this "territoriality" are fossile fuels: they are imported from other territories.

It seems also remarkable that industrial societies, on the level of national economies, overwhelmingly live upon direct extractions from natural environments. This even holds true if water and air are disregarded, as may be gathered from **Figure 6**: 87% of all material goods flowing into the economy per year are "primary products". Construction materials (road stone, sand etc.) constitute the largest fraction: they make up for almost one third. The second largest fraction is food: animal food and grains amount to almost one quarter of the total input[13]. A total of 36 million tons per year of biomass for nutrition is consumed; this amounts to 12.6kg per inhabitant per day. This corresponds to roughly 45 000 kcal/per day and is about twenty times higher than the biological metabolism.

The extraction (or import) of timber (for construction, manufacturing and combustion) amounts to 13%. Thus the direct extraction of biomass altogether accounts for 36% of the solid matter of the inputs a society uses.

The next largest fraction (14%) is made up by fossile fuels; another 4% by metal ores. Thus roughly one fifth of the yearly inputs of an industrial society is extracted from our planet's long term subterrestrial deposits, not regenerable within time spans human societies may count upon.

Let us now look at the "use"-side of the inputs. A large fraction (52 million tons resp. about one third of the total) is put on stock and is added to the already huge amount of buildings, roads, dams and the like. (One should be aware that these stocks as a rule prevent or reduce biomass production, see section 4 of this paper). Almost half of the material input (approximately 75 mio tons) is put to short term uses: nutrition and materials for combustion. Its "off-products" are immediately emitted into the

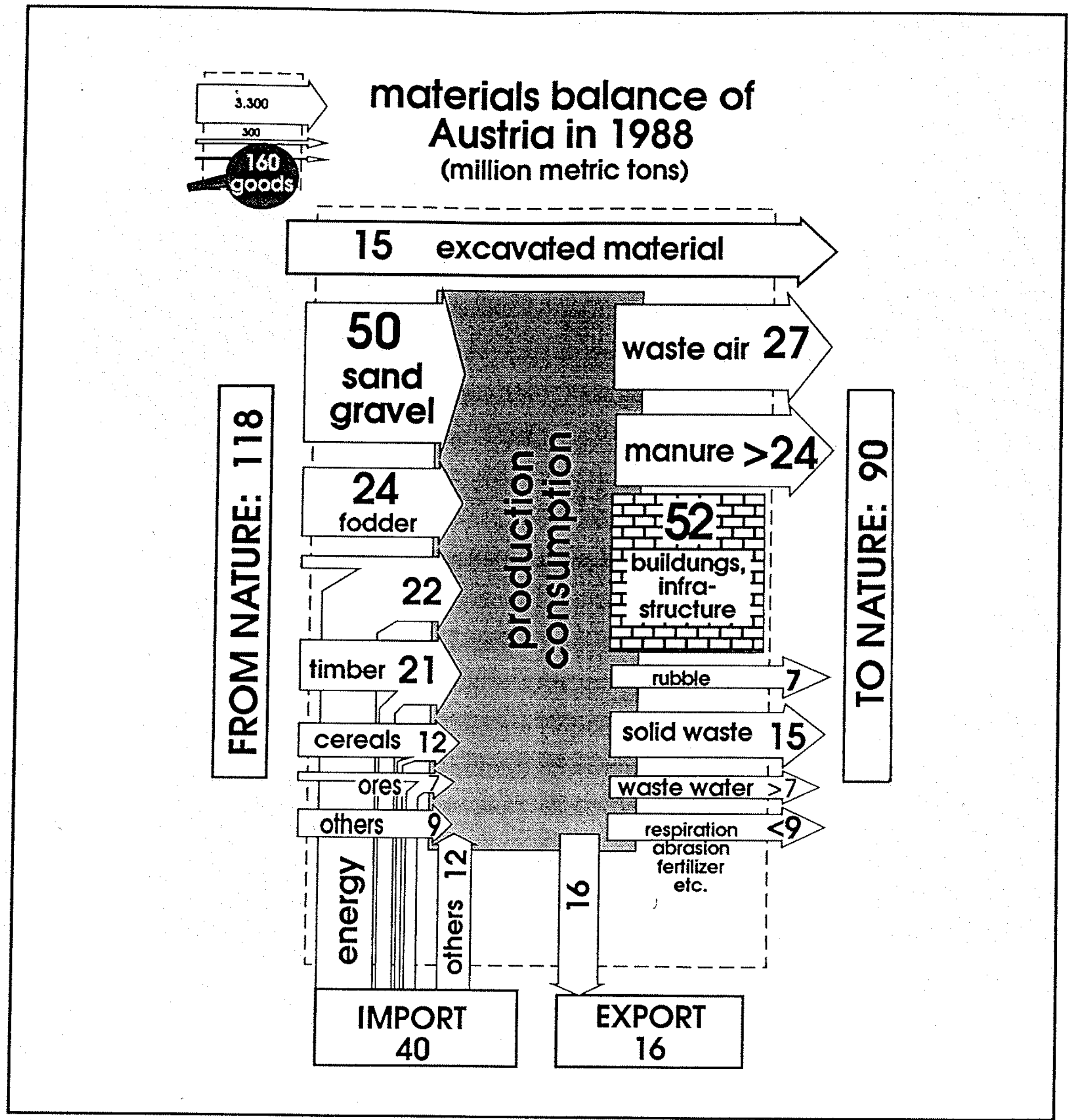

Figure 6: Materials balance of Austria (1988), solid materials only

environment. The rest, amounting to about one fifth, circulates (or is stored) within the system somewhat longer (as Steuer 1992 estimates for 5-10 years) or gets exported to other social systems.

If we apply Meadows' & Randers'(1992) argument on the possibility of decreasing society's inputs from nature by increasing the longevity of its products, one may see that it can apply only to a small fraction of the inputs. Longevity may be a however culturally important, but quantitatively only small contribution to the possible "contraction" of social metabolism: It can work only on one fifth of the inputs. If we triple the life-span (or the recycling periods) of these goods, we arrive at a theoretical potential reduction of 7% of yearly inputs.

A large contribution might be expected from changes in nutrition: An increase in vegetarianism could mean a 10-20% deduction from yearly inputs. Quantitatively almost equally important would be more efficient uses of energy: Increasing energy efficiency and reducing transportation (particularly road traffic) would render another 10% reduction of material input. And finally one could imagine cutting on the net growth of construction and on recycling of construction materials: Maybe this would amount to another cut of 10-20%. All these measures taken together might amount to cutting down half of the society's (solid) inputs from the environment. This would automatically be accompanied be a reduction of oxygen and water inputs. These calculations are very tentative, of course, but they may render an impression on possible changes more reliable than the usual sweeping estimates (e.g. Meadows' & Rander's "factor 8").

Now let us take a look at the "output"-side of **Figure 6**, that Steurer has carefully cross-checked by the Austrian emission- and waste-statistics. The only physical "output" to the natural environment that may be considered as a (however problematic) social contribution to its regeneration are an estimated 24 million tons per year of fertilizers (animal manure). About 50% of the input matter is emitted to the environment in the form of "wastes" more or less detrimental to it (such as carbon in the form of CO_2, sewage or solid wastes to be deposited). The rest is either exported as goods or put on stock.

How wasteful this economy works can be seen more clearly by material input-output analyses of single economic branches, as Payer (1991) has demonstrated[14]: in manufacturing industries ten tons of output in the form of goods correspond to 1-4 tons of output in the form of waste.

The material outputs are of course not equally "harmful" to the environment. Moreover, they can be harmful in different functional contexts, and they may have a different weight in proportion to the natural cycles themselves. As Ayres (1991) showed, human activities currently influence the natural turnover of the carbon-, nitrogen-, sulfur- and phosphorous-cycle (the key cycles of the biomass productivity of this planet) between 5 and several hundred percent.

We will go into the problem of how to judge environmental "harmfulness" within section 5 of this contribution. But so far we tried to argue that the shere size of society's metabolism in terms of matter is a meaningful global parameter for the effect the system will have on its environment. And if "limits to growth" are to be discussed, the only relevant limits are of a physical nature. Monetary values, national incomes and profits may grow as much as they like, as far as the environment is concerned.

4. The colonization of nature by modern industrial societies

"All human groups conciously change their environment to some extent - one might even argue that this, in combination with language, is the crucial trait distinguishing people from other animals ..." (Cronon 1983: 13). This is true for the hunter and gatherer societies of the Paleolithic as well as for modern industrial societies. What has changed are the mechanisms of these modifications, their extent, and their ecological consequences. As we showed in section 2 of this paper, the typical modes of reproduction of societies (pre-neolithic, agrarian, industrial) can be described as a development of different types of interventions into ecosystems.

The typical mode of reproduction of hunter-and-gatherer societies did not differ very much from higher primates except for the use of fire and some simple tools. Since the neolithic "revolution" this has changed fundamentally: whole ecosystems have been and are being altered so that their output could be increased by several orders of magnitude. This is what agriculture, forestry and many other culturally important techniques are all about.

Although this colonization of nature is taking place in order to maintain the physical metabolism of societies, it cannot be reduced to the rather simple idea of input (resources) and output (waste, emission). Societies do not only harvest, they fundamentally alter the functioning of all the natural systems around them. Irrigation systems, for example, change the availability of water, one of the ecologically most important factors in terrestrial ecosystems, on large scales. Societies breed animals and plants in order to increase the production of food.[15] This type of exchange processes between society and nature is quite different to simple "input", e.g. intake of plants or meat as nutrition.

Dams, for example, are built in order to use the energy of the river to generate electricity instead of inundating floodplains or eroding the riverbanks. For the purpose of a water power plant one has to intervene in the structure of a natural system, change its functioning, or, in other words, colonize it. Interventions of this type are made purposively in favor of human benefits, which distinguishes them from outputs like wastes or emissions that may be considered mere side effects of social metabolism. If a road is built, plants are purposively eliminated from this area because they would impede mobility - the concrete used is no "emission" into the environment, but a means to a social purpose. Of course this same road has side effects (such as cutting through habitats) that do not serve a human purpose, and therefore would not be defined as "puposive intervention". Another example: If we wish to increase soil fertility by mineral fertilizers, the output of such fertilizers is a purposive intervention - but not the consequent destruction of soil microbes (which occurs as a side effect). Admittedly there exists a "grey zone" in which attributions and definitions remain ambiguous, though.

If one seeks to describe these purposive interventions on a sufficiently abstract level, one has to ask for the most important properties of the colonization of nature. There are different possible approaches to this question. One may ask which type of environmental problems can be attributed to the colonization of nature. In the contemporary political discourse the most important issues seem to be the loss of biodiversity, the destruction of habitats, landscapes and arable soil, genetic engineering and the maltreatment of animals. These problems refer to different biological levels of intervention: biotope, organism or genom. These are the levels for which we tried to operationalize the intensity of purposive interventions, or in other words, of colonization strategies (Fischer-Kowalski et al. 1991a, Haberl 1991, Wenzl & Zangerl-Weisz 1991): interventions into biotopes, maltreatment of animals and interventions into evolution.

"Intensity of intervention" is a very general notion, and it does not automatically imply a value-judgement concerning the consequences. The background assumption to this might be spelled as follows: The higher the intensity of intervention, the more the living conditions of other species and their evolution are determined by man. This may be interpreted in terms of responsability, in terms of sustainability of man's economy, or in terms of control respectively of imperialism (Galtung 1975). This should be open to political debate: In all cases it seems reasonable to generate informations that provide society with an awareness of its own interventions.

In this section we will discuss some aspects of the interventions into biotopes. Obviously society intervenes into biotopes in many qualitatively different ways, and it would be a difficult task to catalogue them all. It is possible to organize this complexity in a way that allows to mirror the most relevant processes on a reasonable level of abstraction, though. We think that the most important interventions are interventions into the production of photosynthetic energy, into water cycles and into soil chemistry.

- Society completely alters the natural energy flow of ecosystems. Natural habitats are replaced by roads, buildings and the like which prevent the growth of green plants and thereby prevent the natural energy flow. Agriculture and forestry harvest accumulated energy.

- Society massively intervenes into natural water cycles. In Austria for example about 63% of the technically feasible hydropower potential is currently used, which required the transformation of whole rivers into chains of storage lakes. Much of the remaining rivers and brooks have been regulated and ecologically degraded. All these interventions have one common feature: The energy of the flowing water is not ecologically effective any more, either because it is extracted and converted to electrical energy, or because the water is diverted into technical structures (Haberl 1991).

- Agriculture and - to a smaller extent forestry and other sectors -purposively intervene into the most important nutrient cycles in order to increase the fertility of the soil (nitrogen, phosphorous, potassium etc.) and purposively poison competitors with pesticides.

Let us now concentrate on interventions into the production and availability of photosythetic energy.

Energy not only is the motor of the industrial economy, but also for natural ecosystems. Ecosystems can be conceptualized with compartment models, in which more or less closed materials' cycles between the compartments are driven by a flow of free energy (Odum 1983, Odum 1991). The green plants convert radiant energy from the sun into chemical energy in the process of photosynthesis. The accumulated energy is available to all other organisms: The heterotrophic organisms (animals including man, fungi, micro-organisms) depend upon consuming energy-rich substances in order to sustain their metabolism. Consequently, "photosynthetically fixed energy ultimately supports the great diversity of species that inhabit the world's ecosystems" (Wright 1990, p.189).

Net primary production (NPP) is the photosynthetically fixed energy, accumulated by green plants in a certain period of time (usually one year). Empirical studies show that energy flow can be related to numbers of species with species-energy curves (Wright 1990, p. 189). This means that if the amount of energy remaining in the ecosystem is reduced, the number of species living in this ecosystem will diminish (see **figure 7**).

There must be limits to the fraction of NPP which can be used in a sustainable manner. The human appropriation of the NPP is currently estimated to lie between 20 and 40% of the total terrestrial global NPP (Vitousek et al. 1986, Diamond 1987, Wright 1990, Max-Neef 1991). Even if it is not clear at which percentage of human appropriation of NPP the limits of sustainability are reached, the current amount already is considerable, and obviously cannot be increased without further speeding up the extinction of many other species.

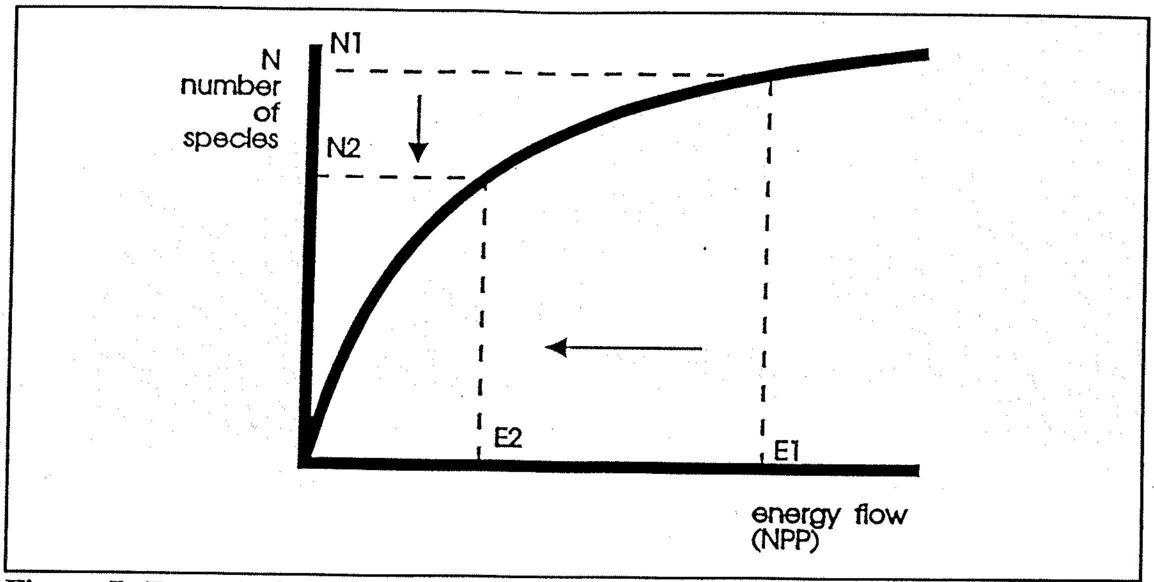

Figure 7: Example for a species-energy curve (Source: Wright 1990)

We have calculated the intensity of intervention into the NPP on Austrian territorry in terms of the NPP "appropriated" by society (see **figure 8**).
We measure it as the difference between the hypothetical NPP of the undisturbed ecosystem and the actual NPP.

socio-economic uses	area concerned km²	photosynthet. fixed energy[1] hypothetical NPP_h (PJ/a)	appropriated by man NPP_a (PJ/a)	distribution of approp. NPP (%)
agriculture[2]	15.900	370	250	40,4
grassland, alpine pastures	21.000	280	180	29,0
forests (logging)	34.300	580	110	17,7
gardens	1.700	40	20	3,2
traffic zones	1.600	40	40	6,5
buildings	700	20	20	3,2
other[3]	8.000	40	0	0,0
total	83.200	1.370	620	100,0

[1] first estimates based on international literature
[2] including wine
[3] indcluding waters and wasteland

Sources: Bundesamt für Eich- und Vermessungswesen 1989; BMLF 1989a; BMLF 1989b; ÖSTAT 1990; own calculations

Figure 8: Appropriation of NPP in Austria 1988 - first estimation (Source: Own calculations)

What does this mean? The hypothetical NPP_h (per space unit and year) depends upon morphological and climatic circumstances. Under Austrian conditions it may vary from about 5 $TJ/km^2.a$ (alpine grasslands) to 50 $TJ/km^2.a$ (floodplains).[16] Would society not intervene, this biological energetic basis would be available to all species. The Austrian society does of course intervene in qualitatively many different ways, but they can be boiled down to two mechanisms:

(1) It builds structures (such as highways or buildings) that prevent or reduce the NPP in a certain area drastically (the same road prevents a certain NPP_h each year by its very existence[17]).

(2) Consumption: Certain amounts of NPP are harvested (or grazed off by cattle) and serve as inputs to society, thereby being no more available to the ecosystem.

What is shown in **figure 8** as NPP_a appropriated by the Austrian society is therefore the sum of "prevented" NPP and "consumed" NPP. The hypothetical NPP on Austrian territory is estimated to be around 1.370 PJ/a. Thus society's share of the products of photosynthesis in Austria (with 620 PJ/a) amounts to about 45% of the hypothetical total production.[18]

About one tenth of the NPP appropriated (or 5% of the possible "natural" production) is due to the shere prevention of plant growth by buildings and roads. About 70% serve nutritional purposes.

The appropriated photosynthetic energy amounts to 80 GJ per capita and year in Austria. This is 20 to 25 times more than the necessary caloric intake (which is 2200 kcal/d or 9.200 kJ/d, times 365 days results in 3,36 GJ/a) per person. It should be noticed, though, that the figure of 80 GJ/a contains not only agricultural or forestry products which are directly consumed by people, but also the intake of cattle, the reduction of productivity of ecosystems caused by roads, buildings, by conversion of forests to pastures and the like. Nevertheless this means that an industrial society like Austria produces and reproduces environmental structures that permit little more than half of the current photosynthetically fixed energy for all other species but human beings.

5. The problem of identifying particularly "harmful" interventions of societies into their natural environment

So far we have attempted to approach the very basics of the exchange relationship between societies and their natural environments. We have been talking about the size and structure of society's metabolism, and we have been talking about some dimensions of colonization that make human societies veritably dreadful competitors for all other species. Changing these basics in favor of long term survival of human societies does, to our understanding, require elementary changes of the industrial mode of production. Whether they will be enforced by environmental pressures or even "catastrophes", or gradually be introduced by anticipatory cultural, economic, political and technological change, or by both, we don't know. But what about the fine-tuning of everyday political and economic decisions, the choices between everyday practical alternatives? Most of the contemporary discussion on "environmental risks", "environmental protection", "environmental politics" and action guided by "environmental consciousness" is centered around these issues.

Beyond a quite widespread conviction that "we harm our environment" and moral appeals that we better should not (see Kahlert 1990), environmental problems mainly enter the mind as contemporary threats to human health. Upon second thought it might appear that we should not really waste so much, and that we better preserve our climate and our landscapes, and finally the altruistic idea that we should also let some other creatures that don't harm us survive and live as they like. These commonsense ideas (among others) are used as guidelines for everyday activities. In order to qualify for an awareness of society's possibly harmful interventions into its natural environment and as a basis for an information system that might record such interventions, some systematization is required.

We suggest the variety of conceptions to be ordered into four basic paradigms:

- "poison paradigm"
- "natural balance paradigm"
- "entropy paradigm"
- "conviviality paradigm".

The "poison paradigm" is probably the most widespread one in commonsense understanding of "environmental problems". It is derived from the scientific traditions of medicine and chemistry. This paradigm views society as producer of (chemical) substances which emitted into the environment cause disturbances that directly or indirectly act back upon society in a noxious way, mainly in a way endangering human health. Environmental regulation is then basically understood as control for noxious emissions. That this paradigm is so dominant in developed industrial societies may well be understood in the light of the innovations to human metabolism introduced by the industrial mode of production: The transformation of huge amounts of subterrestrial resources in outputs to the atmospheric, water and soil-cycles.

The "natural balance paradigm" is rooted in the scientific traditions of biology (also shared by agricultural scientists, climatologists, and most nature-protection agencies). In this line of reasoning society is viewed as an agent who - intentionally or not - intervenes into the functioning of natural systems in a way detrimental to their self-regulation. Thus society is suddenly confronted with a situation in which some natural systems do not function any more in the way society is accustomed to and has learned to rely upon. In this paradigm environmental regulation is understood as protection of the sensitive aspects of biosystems against human intervention. This is quite a different understanding than within the framework of the "poison paradigm". The environment is seen as an array of self-regulating systems in which chemical substances play one part among many other. The very same substance can work once as a nutrient, and at another time (and place) as "poison". And many other interventions apart from chemical substances count: be it the regulation of rivers, the importing of alien organisms or the use of heavy machines. There cannot apriori be distinguished between "harmful" (e.g.noxious) and "harmless" interventions, since this depends entirely upon the sensitivities of the systems concerned.

The "entropy paradigm" is founded in theoretical physics, the so-called laws of thermodynamics, and at the same time relates well to economics. All processes are processes in which energy is used; it is not "used up" though, but only changed in quality: it becomes dispersed, less concentrated. In other words, its entropy increases. In an isolated system each process can only increase, but never decrease entropy - and finally all processes stop (see Prigogine 1990). Within this paradigm society is viewed as s system that exessively contributes to the production of entropy by not confining itself to the use of energy provided by the sun, but by using up energy reserves of this planet stored up for ages. The central environmental question according to this paradigm is therefore the speed with which society uses up (or rather: devaluates) resources in relation to the speed with which they are being reconstructed. Does society live upon natural "income" or upon natural "capital"?

The "conviviality paradigm" is founded in philosophical and ethical traditions that don't consider the human species entitled to exert its rule over all other species on this planet. Nature is not simply viewed as an "environment", but rather as "Creation" to be respected. Society (or often more simply: mankind) is regarded as an apparatus that increasingly dominates more parts of this planet and more life processes of other species and functionalizes them according to its own needs without respecting the needs of others (e.g.Devall 1991). The environmental question to be asked is the following: By which activities does society (unneccessarily) destroy, harm or dominate the living conditions of other species? How can the degree to which mankind lives at the cost of others be reduced?

Each of these paradigms is obviously guided by different reference concepts, but each of them is able to catch important aspects of the possible meaning of "harms" society causes to its natural environment. The paradigms are not mutually exclusive in the sense that one specific aspect of environmental damage might not occur in more than one of them. But they cannot be reduced upon one another, nor can they be merged into one single "grand paradigm".[19] Each has its specific structure of reasoning, its own scientific and political tradition, and its audience: This is why we call them "paradigms" rather than theories. All of them taken together, so we think, permit a fairly complete scanning of what can be meant by society "causing environmental damage"[20].

We think that an adequate understanding of the environmental impacts of societies should bear reference to all these four paradigms, and societies should make themselves aware of their environmental performance by keeping records concerning the central set of variables in each of them. The political imperative, particularly for industrial societies, would clearly be to reduce the amount of physical impacts upon the environment with respect to all four paradigms. All alternatives of human living neccessarily have environmental impacts. The choice between them may be aided by such a screening, but remains a matter of political discussion and decision making process.

In order so serve as guidelines for such decisions the paradigms for environmental impact have to be properly operationalized within a comprehensive information system well connected to established systems of social and economic statistics. We have suggested such an information system to the Austrian Government (and also proposed it on an international level, see Fischer-Kowalski et al. 1992), and we have tried to show that most indicators could be generated by the Central Statistical Office within a reasonably short period, which apparently it will attempt to do.

We chose an approach closely related to the design of the System of National Accounts (SNA) and easily to be linked to (monetary) economic data by means of input-output analysis. All indicators portray some relevant yearly flows between the economy and the natural environment, thus lending themselves to sectoral and time-series analysees common to economic accounting. The information system is self-referential of the

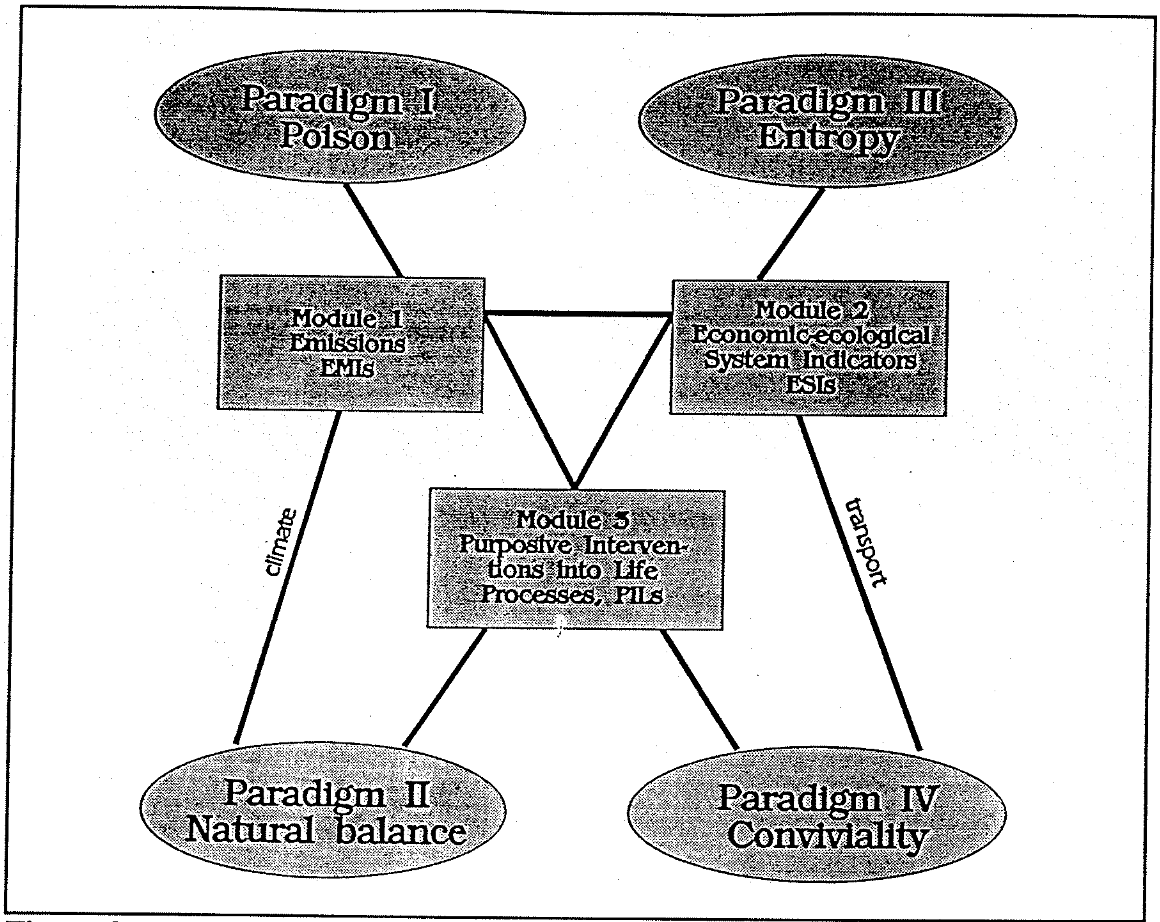

Figure 9: The interrelation of paradigms and information modules

performance of society. This means that it does not portray the degradations or changes within the natural environment induced by social activities, but the indicators mirror environmentally relevant properties of the social system and its physical exchanges with the environment.

The information system consists of the following three modules, listed in **Figure 10** in greater detail:

(1) Economic-ecologic system indicators (ESIs), these being indicators which describe ecologically relevant physical properties, i.e. the "size" of society's metabolism and the overall "ecological efficiency" of the economy, thereby relating to the paradigm of "entropy" (see **Figure 9**)

(2) Emissions (EMIs), selecting for some particularly obtrusive physical outputs of society into its natural environment, which typically occur unintentionally (society does not mind doing without if it can). This is the most obvious and well established module of informations concerning environmental impacts and relates mainly to the "poison"-paradigm, to a lesser extent (such as with CO_2) to the "natural balance"-paradigm (**Figure 9**).

1. ESIs: Ecologic-economical System Indicators

Materials balances
- materials consumption (primary, secondary, total / tons)
- materials wastage (tons)
- materials intensity (tons/AS)

Energy consumption
- net consumption - renewable / not renewable (Joule)
- net consumption of electricity (Joule)

Transport
- passenger kilometers (road / railway)
- ton kilometers (road / railway)

2. EMIs: Emissions

Gazeous emissions
- effect parameter "global warming potential" (CO_2-equivalents)
- effect parameter "ozone depletion potential" (F21-equivalents)
- effect parameter "toxicity" (?)

Liquid emissions
- effect parameter "oxygen consumption" (BSB-5)
- effect parameter "eutrophication" (tons phosphorus)
- effect parameter "toxicity" (?)

Solid emissions
- total waste (tons)
- ?

3. PILs: Purposive Interventions into Life Processes

Interventions into biotopes
- appropriation of net primary production (NPP / Joule)
- interventions into the water household of rivers (Joule.km)
- appropriation of water (m^3)
- release of anorganic fertilizers (tons of N, P, K) and of pesticides (tons)

Violence towards animals
- animal husbandry below a minimum standard for the quality of life (number of animals)
- animal killing below a technical minimum standard / animal experiments (number of animals)

Interventions into evolution
- breeding techniques (?)
- genetic engineering (?)

Figure 10: Proposal for a set of environmental indicators to be connected to the Austrian SNA (Fischer Kowalski et al. 1991a)

(3) Purposeful Interventions into Life Processes (PILs) are no unintentional side-effects of production (like emissions), but are made in favor of a particular social use. These indicators are to portray the environmental impacts of society's strategies of colonization. They relate both to the "natural balances"- and to the "conviviality"-paradigm (**Figure 9**).

Admittedly there is a long way to go from generating informations on society's environmental performance to generating the political will and ability to regulate it. But at least such informations provide a neccessary technocratic link.

6. Conclusions

The current debate on environmental problems is characterized by fundamental misunderstandings. There are different groups of actors, which have completely different perceptions of environmental problems, rooting in different "unifying concepts" within the different scientific traditions. We think that it is necessary to be aware of these differences, and to accept the legitimacy of basically different points of view (we called them "paradigms"). This is a precondition for a rational and democratic political bargaining process.

In a broad historical overview we have tried to show that human societies have been producing "environmental problems" for themselves since their very existence. They have been trying to cope with them by the cultural regulation of population growth (and its spacial distribution), and by the cultural evolution of new modes of production. Each mode of production corresponds to specific exchange-relations between societies and their natural environments. We have distinguished two types of exchange-relations that we termed "metabolism" and "colonization".

Metabolism refers to physical input-transformation-output processes between societies and their natural environments: Natural resources are "ingested", processed internally and released into the environment. Society's metabolism can be related to a biological minimum that equals the sum of the metabolisms of the human beings that make up society. History may be written as an enormous increase in this metabolism: per capita the metabolism of a member of an industrial society, as empirically exemplified for Austria, amounts to 15-20 times the metabolism of a (well nourished) member of a hunter-and-gatherer society. A member of an industrial society consumes 15-20 times the amount of biomass, 20 times the amount of water and about 10 times the amount of air his/her individual metabolism would require. This of course puts an enormous pressure upon the environment. In the course of human history changes in the mode of production never reduced, but always enhanced the metabolism per capita (despite the fact that the average living conditions resulting from this often were more miserable than before). The metabolism changed in quality, though. Environmentally speaking, the great invention of the industrial mode of production consisted in using subterrestrial resources (such as fossile fuels, in addition to metal ores) far away from the life interests of other species and therefore not competing with them, thereby depleting the base of human nutrition. The troubles with this, though, are not only the limited amounts of such resources (which will be heavily felt for generations to come), but the release of the off-products of such transformations into the "wrong" natural cycles, causing disturbances in the self-regulatory processes of natural systems societies so far relied upon. As we have tried to estimate, the size of the metabolism of industrial societies could theoretically be reduced to 50% of its current size by measures that basically adhere to the established standards of the industrial mode of production such as efficiency and an optimization of the relation between means and ends. This need not neccessarily interfere with the "golden calve" of economic growth: Monetary growth (largely determined by the value of human labor) is environmentally irrelevant, it's only physical growth that counts. If growth is achieved by a more intelligent organization of human labor and a more effective utilization of natural resources, it is ok.

"Colonization" refers to another type of exchange relations between societies and their natural environments. This exchange-relation is a prerequisite to metabolism; it cannot be described within the logic of input-output-models, but rather within the logic of domination. It encompasses a set of purposive interventions into living systems that change some aspects of their functioning (but still relies upon their self-regulatory properties) in order to make them more exploitable for social needs. Colonization strategies were the very invention of the neolithic revolution and have also undergone changes by each mode of production. Within the industrial mode of production innovations in colonization were neglected for a long time. All colonization techniques (or, as we termed them more operationally in section 4, all "purposive interventions into live processes", PILS) act within the framework of competition with other living species and intentionally influence biological evolution. The most "classical" of these interventions is the appropriation of the energy accumulated by green plants by either harvesting it for nutritional and other purposes, or by artificially reducing its production (for example by built structures). We were able to show empirically that an industrial society like Austria at the time being appropriates almost half of the bioenergetic resources on its territorry and channelles them into social uses: per inhabitant this amounts to about twenty times the neccessary caloric intake of a human being.

Moscovici (1990) has termed the industrial society's paradigm of nature *"mechanical"*, which is characterized by the dominance of mechanical and chemical methods: the "clockwork nature". He sees a new paradigm arising which he calls *"cybernetic"*. It is characterized by qualitatively new and enhanced possibilities of human control over nature. They mainly refer to what we termed "colonization strategies": The application of analytical-chemical methods in ecology yielded new possibilities of directing and utilizing natural processes in order to meet human demands (Korab 1991). New biological technologies are developing rapidly and are politically strongly promoted - last but not least because it is hoped that they will be the urgently needed "clean technologies". There exists a tendency of replacing technical forms of metabolism by strategies of colonization, for example by using biological (genetic engineering) instead of chemical techniques (Fischer-Kowalski et al. 1991b).

We are convinced that such a technological change may outdate some environmental problems but at the same time induce new ones. We have therefore outlined an environmental information system that should permit to monitor both types (the "metabolistic" as well as the "colonizing" type) of exchanges with the natural environment and serve as a guideline for a general strategy of reduction of interventions. The industrial life style the way it works now cannot possibly be generalized for all human beings on this planet, let alone for the generations to come. Since it serves as a strong model many (if not all) societies struggle to imitate, this way of living has to change. We are quite convinced that its bearers will be no less happy with half of the physical turnover they require now.

Notes

1. This article is to be seen as as an outcome of a team research process. We particularly wish to acknowledge the contributions of Thomas Hartmann-Macho, Harald Payer and Anton Steurer (all IFF-Soziale Ökologie, Vienna) and the careful reviewing by Stefan Bringezu (Wuppertal-Institute).

2. Although attempts in this direction are becoming somewhat more common now, see for example Pearce et al.1990 and the international examples given there, or Ayres 1991.

3. Cultural evolution may nevertheless, and typically does, induce biological evolution by changing the conditions for selection in the environment. The increase in number and improving hunting techniques of early hunter-and-gatherer societies have probably contributed to the extinction of the pleistocene megafauna in the Old and the New World (Harris 1990, p.38). The development of urban agglomerations supported the evolution of various microbes that consequently caused epidemical catastrophes (Crosby 1990, pp.193), AIDS being one of the latest examples of such a process.

4. The approximately 2200 kcal per organism and day needed, have to be extracted from biomass (since humans are heterotrophic organisms that cannot live on sunlight and anorganic matter). The builtup of biomass can be described energetically: about 0.4% of photosynthetically active sunlight is incorporated into plants as human edible matter (Harris 1991, p.83). If humans choose to eat animal meat, this ratio is decreased by 10^{-1}, making 0.04% photosynthetically active sunlight available for human nutrition.

5. Birdsell (1968) calculated infanticide-rates from data gathered on Australian aborigines still living by a hunter-and-gatherer mode of production. He arrived at an estimate of 50%.

6. In the biological cycle "feces" serve as fertilizers of soil and thereby contribute to the regeneration of nutrients. This is a nice invention of evolution, but has little to do with the intentions of human beings: they have to get rid of their feces, whether this contributes to fertilization or not. The use of feces for intentional fertilization may be socially organized, though. A more recent example for this was given during the Chinese cultural revolution when big cities were organized to contribute to soil fertility by transporting human feces to the countryside. More "civilized" societies, inspired by the British example of WC, socially organize the deletion of human feces to surface waters thereby "overfertilized".

7. The protection of the environment from "exploitation beyond reproduction" in hunter-and-gatherer-societies had probably to be achieved by cultural means, too. Duby (1984, p.70) for example reports on strong taboos against the cutting of trees in 6th century Europe that Christianity had difficulties to overcome inspite of an abundance of undernourished people.

8. There was no steady growth of population, though. In the centres of the large irrigation cultures such as in China, India or Egypt there were periods of population growth, periods of population reduction and periods of stagnation. For centuries the standard of living in China, Northindia, Mesopotamia or Egypt remained constantly just a little above or below the level of impoverishment. If the population density of some region increased above a certain level, the level of living fell below misery; this led to wars, famines and a reduction of the population (Harris 1990, p.198)
Similarly the European population was substantially reduced in the course of the collapse of the Roman Empire and the peoples migration between the 2nd and the 7th century (Duby 1984, p.20) and then again during the 14th century as a consequence of famines and plagues (Bowlus 1988).

9. Important innovations in the agriculture of the 16th to 18th century were crop rotation with lucerne (bearing symbiontic bacteria able to bind atmospheric nitrogen), enhanced husbandry of livestock and the introduction of the potato (Wahlert and Wahlert 1981). In 1840 Justus von Liebig discovered the principles of chemical fertilization. The technology for the production of soluble nitrogen from atmospheric nitrogen was invented by Fritz Haber at the beginning of the 20th century. The practical application of these inventions on a mass scale is a fairly young phenomenon.

10. "Growing" with respect to the size of its metabolism, which is both a function of its size of population and its mode of production. The per capita metabolism of Western Europeans in terms of mass and energy is at least 20 times higher than the more or less biological minimum required by an Australian aborigine see further down).

11. The biological respiration process of humans is not included in this calculation, though. Wheras about 110 kg (or 80 kubic meters) of air per day are put through combustion processes (per inhabitant), humans need about 10 kubic meters (or 13.7 kg) per day for their respiration.

12. But not air used for cooling purposes and as pressurized air. These amounts seemed too difficult to calculate.

13. Animal meat, if "produced" in Austria, was regarded not as a primary product (except for deer from hunting, which is quantitatively negligible), but as secondary, primary product being the vegetable basis of animal feeding (see Steurer 1992, p.8)

14. The need for a supplementary system of physical accounting connected to the traditional SNA has gained understanding during the last years. Ambitious attempts have been started by the Norwegian, the French and the Canadian governments (see Corniere 1986, Friend 1988, OECD 1988). The model of material balances presented here is to be seen as a contribution to that discussion in progress.

15. Some authors even argue the success in this primary colonization of plants and animals to be the major explanatory variable for the longterm dominance of European civilization over all other civilizations (e.g. Crosby 1990)

16. 1 TJ = 10^{12} J; 1 PJ = 10^{15} J

17. There may also be cases in which the intervention causes an increase of NPP above the "natural" level, such as by growing maize instead of wood. But in practically all such cases this surplus NPP is then extracted from the ecosystem by harvesting, resulting in an overall minus.

18. It is interesting to note that the amount of appropriated photosynthetically fixed energy corresponds quantitatively to the end use of (technical) energy, which for Austria is around 750 PJ/a.

19. The notion of "sustainability" claims to be such a "grand" paradigm. But inspite of its generality we think it cannot embrace all aspects these 4 paradigms encompass. It excludes the "conviviality"-reasoning (paradigm 4) completely, and it would rule out some of the more short-term processes in the "poison"-paradigm. It seems a close relative to the "entropy"-paradigm, also sharing its unspecificity.

20. It is interesting to note that there exists a vast amount of (often: natural science) literature elaborating on either specific stresses upon the environment on the one hand, global concepts (such as "risk society" or "sustainability") on the other hand, but very few attempts at a classification of environmental impacts of societies in a systematic manner. To our mind this is due to the diversity of scientific traditions dealing with environmental problems and their lack of conceptual communalities. The classification we suggest here therefore is rather a decriptive one: It tries to assemble the approaches chosen in the various (often disconnected) discourses, trying to link to each major tradition. We have "tested" this classification in several interdisciplinary contexts and found it to provide a reasonable link for understanding without any "hegemonial" pretense.

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