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Society's Metabolism

On the Development of Concepts and Methodology of Material Flow Analysis. A Review of the Literature.

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SOCIETY'S METABOLISM
On the Development of an operational Concept for the interactions between society and its environment

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Introduction

In one of the founding articles on environmental sociology, Catton & Dunlap (1978) claimed it would not suffice if environmental sociology turned into just another sub-hyphen of the discipline. Instead, it would have to offer a new paradigm, a fundamental concept of society differing from the hegemonic „human exeptionalism paradigm". This new paradigm should view humans as but one of many species interlaced in the „web of nature", in which purposive human action produces many unintended consequences, and it should accept that the world is physically and biologically limited (45; see also Catton & Dunlap 1980). This paradigm should support the study of interaction between society and the environment, the core task of environmental sociology (Schnaiberg 1980). Could a view of society as having a material and energetic metabolism and, therefore, depending upon continuous energetic and material flows from and to its environment, provide a core concept of such a paradigm? And could the study of the social (i.e. economic, technological and cultural) regulation of society's metabolism become a genuine sociological task of highly practical value in view of the ecological problems confronting industrial society? Contemporary research on human-induced global environmental change increasingly deals with two broad and overlapping fields of study[1]: One of them is industrial metabolism,[2] focusing on the flow of materials and energy in modern industrial society through the chain of extraction, production, consumption and disposal. This has been subject to multidisciplinary work engaging mainly scientists from physics, chemistry and engineering, from the life sciences and from economics. Sociological competence so far has hardly entered the field.[3]

In this essay I am going to investigate how the concept of metabolism *has* been applied to human social systems, and how it *can* be applied. I will first elaborate on the biological and ecological meaning of this term and review some of the early uses of this notion in sociology, cultural anthropology and social geography.[4] I shall close this first part by discussing some of the the epistemological preconditions for the „import" of this term into sociological theory and tentatively suggest how some of the problems could be resolved.

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[1] See for example National Research Council (1990), UN-Handbook (1993), European Commission (1994), Enquete Komission (1994), SCOPE (1996)

[2] The second one concerns land-use / land-cover change, and deals with the alteration of the land surface and its biotic cover.

[3] Take as an example the authors of the classic book, edited by Ayres & Simonis in 1994: „Industrial Metabolism". Out of 22 writers, 9 are from physics, chemistry or technical engineering; 6 from the life sciences; 5 economists and, finally, 2 sociologists resp. historians.

[4] What readers might consider an important omission, I did not do a specific inquiry into the history of economics, though. Particularly the type of resource economics practised during times of war (e.g. Paley Report 1952), and equally the history of economic input-output-analysis (see Leontief 1970) would be promising areas.

The awakening of environmental awareness and the increase in cultural acceptability of a critical view upon economic growth during the late sixties triggered a breakthrough of concern for society's metabolism under a new perspective (Wolman 1965, Ayres & Kneese 1968, 1969, Neef 1969, Meadows et al. 1972, Daly 1973). Subsequently there followed more than two decades of relative stagnation: the „size" and „growth"-perspective receded behind the predominance of pollution and toxicity, and sociologists focussed on enviromental (social) problems and movements. Now, in the nineties, there is a virtual explosion of research dealing with industrial metabolism, and the term itself was (re)born (Baccini & Brunner 1991, Ayres & Simonis 1994, Fischer-Kowalski & Haberl 1993, Lehmann & Schmidt-Bleek 1993) as a powerful unifying concept to relate the functioning of society to its consequences upon the environment. Such an explosive situation, however, does not facilitate the task of a reviewer, so I have to ask for forgiveness about the inevitable omissions. Finally the conclusions will focus on what has been achieved, and what could be the theoretical, methodological and practical implications for environmental sociology - or even sociology at large - in need of social change towards a more „sustainable development".

Metabolism in biology and ecology

One of the standard textbooks in biology, Purves et al.(1992, 113), reads:
„To sustain the processes of life, a typical cell carries out thousands of biochemical reactions each second. The sum of all biological reactions constitutes metabolism. What is the purpose of these reactions - of metabolism? Metabolic reactions convert raw materials, obtained from the environment, into the building blocks of proteins and other compounds unique to organisms. Living things must maintain themselves, replacing lost materials with new ones; they also grow and reproduce, two more activities requiring the continued formation of macromolecules." Or, somewhat further down: „Metabolism is the totality of the biochemical reactions in a living thing. These reactions proceed down **metabolic pathways**, sequences of enzyme-catalyzed reactions, so ordered that the product of one reaction is the substrate for the next. Some pathways synthesize, step-by-step, the important chemical building blocks from which macromolecules are built, others trap energy from the environment, and still others have functions different from these."(130)

Similarly it is explained in Beck et al.(1991, 175), another classic: „Metabolism includes the following processes:
* All the chemical processes by which food and its derivatives are broken down to yield new building blocks and energy. This segment of metabolism is termed **catabolism**.
* All the chemical processes by which living cells and tissues are produced and built up. This is **anabolism** (build-up of new molecules by biosynthesis).
* All the regulatory mechanisms that govern these intricate systems."

Whereas the concept of metabolism is widely applied at the interface of biochemistry and biology when referring to cells, organs and organisms in biology, it seems a matter of dispute to use this term on any level further up the biological hierarchy. E.P.Odum, one of the leading system ecologists, clearly favors to use terms like „growth“ or „metabolism“ on every biological level from the cell to the ecosystem (e.g. 1983, 7). A statement like the following from Beck et al. (1991, 679) „The metabolism of the whole body is simply the sum of all the metabolic processes in all the cells of the body“ is not controversial in biology: To aggregate cells to an organism seems to be always legitimate. Which processes may and should be studied on hierarchical levels beyond the individual organism, though, is a matter of debate dating back to Clements (1916) and still ongoing.[5] Basically this is a debate about „holism“ (or organicism) vs. „reductionism“. Do populations (i.e. the members of a species), communities (i.e. the total of living organisms in an ecosystem) or ecosystems (i.e. the organisms and the effective inorganic factors in a habitat) have a degree of systemic integration comparable to individual organisms? Does evolution work upon them as units of natural selection? These questions are contested in biology, and thus a use of the term „metabolism“ for a system constituted by a multitude of organisms does not pass unchallenged. What would be challenged is not the energy conversion and the nutrient cycling in ecosystems - this is taken as a fact. The tough point is whether there exist any kind of controls, information-mediated feedback cycles, or evolutionary mechanisms working on the systems level as such - and not just via individual organisms.[6] Notwithstanding the answers to these questions, it is widely accpted that in effect biotic communities and ecosystems have self-organizing properties that allow them to optimize the utilization of energy and nutrients.[7]

According to these standards, it is obvious that humans maintain a metabolism. As any other animal they are heterotrophic organisms, drawing their energy from complex

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[5] Tansley (1935) established the term „ecosystem“ as a proper unit of analysis. He did so by opposing Clements' „creed“ in an organismical theory of vegetation; he also opposed the term „community“ by arguing it did not seem legitimate to lump together animals and plants as members too different to be put on equal footing (296). Lindemann (1942) then proceeded to analyze ecosystems in terms of energy conversion mathematically, with plants being the *producer* organisms to convert and accumulate sun radiation into complex organical substances (chemical energy) serving as food for animals, the *consumer* organisms of ecosystems. Following death, every organism then is a potential source of energy for specialized *decomposers* (saprophagous bacteria and fungi) thereby closing the cycle in generating inorganic nutrients for plants. This is basically what Odum refers to when talking about the metabolism in an ecosystem.

[6] See the more recent debate of Engelberg & Boyarsky (1979) und Odum & Patton (1981) about the cybernetic nature of ecosystems. Engelberg & Boyarsky claim the dominant interaction between different populations of an ecosystem to be the exchange of brute (informationally unspecific) matter and energy in the absence of information-mediated feedback-cycles. Odum & Patton do also see the food web (as an interconnection of conservative rather than informational processes) as the most fundamental element of ecosystems, but claim a secondary information network to be superimposed upon this network of conservative flows. A somewhat similar debate is carried on by Salt (1977) as contradicted by Edson et al.(1981) on the existence of „emergent properties“ in ecosystems to be distinguished from merely „collective“ properties.

[7] Lotka proposed already in 1925 a „law of maximum energy in biological systems“; similar arguments are presented in theories of succession and climax in plant communities (Odum 1959, 1969).

organic compounds (foodstuff) that have been (directly or indirectly) synthesized by plants from (mainly) air and water utilising the radiant energy from the sun. The human organism converts most of these organic compounds („biomass“) by respiration (utilizing oxygen from the air) into carbondioxide and water, thus extracting chemical energy.[8] The metabolic rate is roughly determined by body weight energetically (so humans fit into the scale of mammals somewhere between dogs and horses), and by physiology qualitatively. Humans can only digest certain foodstuffs, and they cannot synthesize all the amino-acids they need from carbohydrates alone (as most herbivorous animals can). So far go thermodynamics and biochemistry, and there humans certainly are no exception to any rules. If humans are to survive and to reproduce, they must be able to sustain their metabolism.

Since humans are social animals with an ability to communicate and to cooperate beyond that of any other known species,[9] they have tended to solve this problem collectively. It makes sense, therefore, to look at human communities and societies as organizations serving human survival. Societies will, in effect, sustain a metabolism that at least equals the sum of the metabolisms of their human members. If they cannot maintain this metabolic turnover, their populations will die or leave them. But if there is a surplus, this will rarely be processed through the cells of the human body. From an ecosystem perspective, for example the materials birds use in building their nests constitute a relevant material flow associated with birds. In ordinary biological language, however, it would never be considered as part of a bird's metabolism, irrespective of the fact that it may be vital for the bird's reproduction. So, in fact, the concept „metabolism“ needs to be expanded to encompass material and energetic flows and transformations associated with „living things“ but extending beyond the anabolism and catabolism of cells. Whether it is a population or some other entity, the overall material and energetic turnover of a subsystem of an ecosystem, its consumption of certain materials, their transformation and the production of other materials may be an ecologically useful parameter. In biology, even less so in biochemistry, this would not be called metabolism.

We know about humans, of course, that they sustain at least part of their metabolism not by direct exchanges with the environment (as they do, for example, in breathing), but via the activities of other humans. This is a matter of organization. Any attempt to describe this organization in terms of a biological system - whether it be the organism, or a population in a habitat, or an ecosystem - does have to draw on analogies and runs the

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[8] About three quarters of this energy are dissipated as heat, the rest directly participates in body-functions. However, with one exception, even this fraction is eventually converted into heat. The single exception arises when the muscles perform external work - creating either potential energy by lifting a mass against gravity or kinetic energy by, for example, turning a wheel.

[9] For the extraordinary importance of spoken language see Diamond 1992.

risk of being reductionist.[10] On the other hand, the concept of metabolism in biology has valuable features: It refers to a highly complex self-organizing process which the organism seeks to maintain in widely varying environments. This metabolism requires certain material inputs from the environment, and it returns these materials to the environment in a different form.

Roots and traces of metabolism in the social sciences

Metabolism in sociological theory

Within the 19th century foundations of social theory, it was Marx and Engels who applied the term „metabolism“ to society. „Metabolism between man and nature“ is used in conjunction with the basic, almost ontological, description of the labour-process. „The labour-process...is human action with a view to the production of use-values, appropriation of natural substances to human requirements; it is the neccessary condition for effecting exchange of matter between man and nature; it is the everlasting nature-imposed condition of human existence, and therefore independent of every social phase of that existence, or rather, is common to every such phase“ (Marx & Engels 1867, 183f). The „elementary factors“ of the labour-process are: 1. the personal activity of man, i.e.work itself, 2. the subject of work („Arbeitsgegenstand“); and 3. its instruments (ibid, 178). „In the labour-process ... man's activity, with the help of the instruments of labour, effects an alteration, designed from the commencement, in the material worked upon. The process disappears in the product; the latter is a use-value, Nature's material adapted by a change of form to the wants of man.“(ibid, 180). The subject of labour may be „spontaneously provided by nature“ or it will have been „filtered through past labour“.

„...the intentional structure of the labour-process is, for Marx, a transformative one“, claims Benton (1989, 66). This view does not, so Benton says, properly encompass all forms of labour, particularly not what he terms „eco-regulation“(e.g. most of farm work) and „primary appropriation“ (hunting, gathering, mining...), those types of labour closest to natural processes. It also does not cover unintended consequences and various other ecologically important characteristics of the labour process. Thus, Benton concludes, as Marx's and Engels' theory presents itself in the mature economic writings, it bears several theoretical defects „... the net effect of which is to render the theory incapable of adequately conceptualizing the ecological conditions and limits of human need-meeting interactions with nature.“(Benton 1989, 63)

[10] It is interesting to note that biologists tend to attribute organismic (or system integration) characteristics to the human society where they might deny them to an ecosystem. For an early example see Tansley (1935, 290). For a critical discussion see Oechsle 1988.

Marx's and Engels' notion of metabolism was molded by the biology of their times and popular writings from physiological materialists like Moleschott (1857)[11] differing from modern textbooks. It does imply a higher degree of interdependence between man and nature, and more of a relation on equal terms, than the widespread simple idea of man „utilizing nature". The notion points to a fundamental material interrelatedness on an anthropological rather than on a societal level. In other contexts Marx uses the expression „societal metabolism" as an analogue to describe the exchange of commodities and the relations of production within society (see Schmidt 1971, 92).

The writings of Marx and Engels are about the only reference to societal metabolism to be gained from the „founding fathers" of modern social science. While most social scientists tended to be highly interested in the advances of biology of their times, it was mainly evolutionary theory and its implications for universal progress or the healthiness of competition that attracted their attention (e.g. Spencer 1862, Morgan 1877).

There is another angle, however, from which considerations of societal metabolism derived, and this had to do with physics rather than biology: energetics.[12]

The process of societal advance and the differences in stages of advancement among societies can be accounted for by energy: the more energy consumed, the greater the advancement, states Herbert Spencer in his *First Principles* in 1862. Sir Patrick Geddes, co-founder of the British Sociological Society in 1902, sought to develop a unified calculus based upon energy flows and capable of providing a coherent framework for all economic and social activity (Geddes 1884), an attempt "rewarded with near-instant oblivion", according to Rosa et al.(1988, 150). Wilhelm Ostwald, 1919 winner of the Nobel prize in chemistry, had a somewhat similar contribution to make: The more efficient the transformation from crude energy into useful energy, the greater a society's progress. This work provided Max Weber (1909) with an opportunity for an extensive discussion. Weber reacted in quite a contradictory, even double-bind manner. On one hand he dismissed Oswalds approach as „grotesque"(401) and as „mischief"(381), and challenges its core thesis on natural science grounds: In no way would an industrial production be more energy efficient than a manual one - it would only be more cost efficient (386f.). At the same time he rejects natural science arrogance towards the „historical" sciences and the packaging of value-judgements and prejudices in natural science „facts"(401). On the other hand, although, he admits that energy may possibly be important to sociological concerns (399; see alsoWeber 1904); he has never elaborated such considerations.

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[11] According to Schmidt (1971, 86), Marx drew much of his understanding of metabolism from this source and imported a notion of the trophical hierarchy, food chains and nutrient cycling rather than an organismic, biochemical interpretation of metabolism. Besides it should be noted that the German word „Stoffwechsel" literally means „exchange of substances" (between A and B), and does not so much convey a meaning of chemical conversion as the latin term.

[12] My task of reviewing the literature was greatly facilitated by the excellent review of Rosa et al.(1988).

Frederick Soddy, another Nobel laureate in chemistry, also turned his attention to the energetics of society, but did so with an important twist: He saw energy as a critical limiting factor to society and thus was one of the few social theorists sensitive to the second law of thermodynamics (Soddy 1912, 1922, 1926). Similarly, Werner Sombart (1902, II, 1137f.) in his analysis of late 18th century development at least recognized the social relevance of energy: the scarcity of fuel wood, according to him, was at that time seriously threatening the advancement of capitalism altogether. In the mid-fifties Cottrell (1955) raised the idea that available energy limits the range of human activities. According to him this is one of the reasons why pervasive social, economic, political and even psychological change accompanied the transition from a low-energy to a high-energy society.

For the development of sociology as a discipline these more or less sweeping energetic theories of society remained largely irrelevant. Later authors like O.D.Duncan who operated with the term „ecological complex", implying a web-like interdependence among population, organization, environment and technology („POET"-model), carefully circumvented any references to natural conditions or processes. What Duncan calls the environment is devoid of physical characteristics. It is a social, and at best a spatial variable (Duncan 1959, 1964), as it had been for the Chicago-based school of social ecology (Park 1936).

Before the advent of the environmental movement,[13] sociology just did not refer to natural parameters as either causes or consequences of human social activities. Neither the system- nor the interaction-oriented US-American traditions, nor the „materialist", marxist traditions revived in the Sixties, dealt with possible physical properties of society and society-nature-interaction. I feel strongly supported in this judgement by the review of Dunlap & Catton (1979) focussing on the American literature. As one of the few exceptions they mention Sorokin's, as they say, underrated analysis of the social repercussions of famine (Sorokin 1942, 66-67, 122, 262-264, 289). Some of the French mergers between Durkheim, social history and Marxism, such as Foucault (1976) or Bourdieu (1985), at least invite the human body to the sociological stage. The same can be said about the German sociological theorist Elias (1969). Looking at other major macro-sociological European theorists such as Giddens (1989, 1990), Habermas (1981) or Luhmann (1984, 1986), one will search in vain for concepts referring to material dimensions of the society-nature interaction. More recently, some authors do introduce metabolism as a core concept of sociological theory, such as Hamm (1996, 41f).

[13] see Benton (1991) for the importance of social movements for bridging the scientific gap between biology and sociology.

Metabolism in cultural and ecological anthropology

The beginnings of cultural anthropology were, similar to sociology, marked by evolutionism (as in the works of Morgan 1877), and cultural anthropology then split into a more materialist and a more culturalist tradition. The materialist line, from which contributions to societal metabolism should be expected, did not, as was the case in sociology, turn towards economics and distributional problems, but retained a focus on the society-nature-interface. In effect, several conceptual clarifications and rich empirical material on societies' metabolism can be gained from cultural, or, as the more materialist branch is termed by Orlove (1980), ecological anthropology.

Leslie White, one of the most prominent anthropologists of his generation, rekindled interest in energetics. For White, the vast differences in the types of extant societies could be described as social evolution, and the mechanisms propelling it were energy and technology. "Culture evolves as the amount of energy harnessed per capita and per year is increased, or as the efficiency of the instrumental means (i.e.technology) of putting the energy to work is increased" (White 1949, 366). A society's level of evolution can be assessed mathematically: it is the the product of the amount of per capita energy times efficiency of conversion. So this in fact was a metabolic theory of cultural evolution - however unidimensional and disregarding environmental constraints it may have been.

Julian Steward's „method of cultural ecology“ (Steward 1968) paid a lot of attention to the quality, quantity and distribution of resources within the environment. His approach can be illustrated from the early comparative study „Tappers and Trappers“ (Murphy & Steward 1955). Two cases of cultural (and economic) change are presented, in which tribes traditionally living from subsistence hunting and gathering (and some horticulture) completely change their ways of living as a consequence of changing their metabolism. The authors analyze it as an irreversible shift from a subsistence economy to dependence upon trade.

Eastern Montagnais, in the northeastern Algonkin, used to live in multi-family winter hunting groups, and in somewhat larger units during the summer season of fishing and caribou-hunting. Upon the establishment of white trading posts, the trapping of fur-bearing animals and trade for hardware and foodstuffs was secondary to native subsistence activities. „The Indians could devote themselves to the luxury of securing trade articles only after assuring themselves of an ample food supply.“(337) By the use of barter and credit systems, though, they became dependent upon the traders, and finally fur trapping became more important than hunting for subsistence. This resulted in a complete restructuring of their patterns of settlement and communal ties (with a strengthening of nuclear families and territorial family property at the expense of interfamilial ties).

The second example is given for the Mundurucú, native Indians originally living in semi-sedentary villages in the gallery forests and savannah lands in the state of Pará, Brazil, on slash-and-burn horticulture and hunting, until they are drawn into „the ecology of rubber collection". The authors give a more elaborate description of the metabolic transformations.

„During the nineteenth century (and to the present day) the Mundurucú, like the Algonkians and in fact most aborigines, had been acquiring a seemingly insatiable appetite for the utilitarian wares and trinkets of civilization... Firearms, ...clothing, ...(but) also ...many strictly non-utilitarian goods, such as ...raw cane rum and beads. Reliance upon manufactured goods entailed further dependence upon many adjuncts of these goods. For example, firearms required powder and lead, while garments of factory-woven cloth had to be made and repaired with scissors, thread and needles. The substitution of metal pots for native ones of clay and of manufactured hammocks for the native product has reached the point where many young women do not know how to make these articles. ...they would be helpless without the copper toasting pan used to make maniok flour....Despite the flourishing trade in gewgaws, the allure of most trade goods lay more in their sheer utility than in their exotic qualities. The increased efficiency of the Mundurú economy made possible by steel tools must have been enormous."(344f.)

Translating this analysis into the terms of „metabolism" (a concept the authors do not apply), the following transformations have taken place:1- the substitution of metabolism based upon the natural environment by a metabolism based upon exchange with other societies, whereby these cultures become „primary producers" or „extractors" in a social division of labor on a grander scale, and 2- the substitution of certain materials and sources of energy by others, produced and distributed by completely different mechanisms on a completely different spacial scale. These changes in metabolism contribute to a transformation of many social and cultural features of these communities.

Several outright analyses of metabolism have been produced by authors that Orlove (1980) groups together as „neofunctionalists": Marvin Harris, Andrew Vayda and Roy Rappaport. The followers of this approach, according to Orlove (1980, 240), „see the social organization and culture of specific populations as functional adaptations which permit the populations to exploit their environments successfully without exceeding their carrying capacity." The unit which is maintained is a given population rather than a particular social order (as it is with sociological functionalists). In contrast to biological ecology, they treat adaptation not as a matter of individuals and their genetic success, but as a matter of cultures. Cultural traits are units which can adapt to environments and which are subject to selection.[14] In this approach, human populations are believed to function within ecosystems as other populations do, and the interaction between

[14] Orlove's criticism of the inadequate use of biological terms, in this case of group selection as a mechanism not accepted by biological theory (Williams 1966), appears as too harsh, indeed. The unit to which the selection applies, is not the population as such. Cultural maladapation to an environment may in fact decimate a population, but the effect this may have upon the genetic composition of consecutive populations in this environment certainly is not the cause for whatever cultural changes may occur. (Harris 1991, 33-45)

populations with different cultures is put on a level with the interaction of different species within ecosystems (Vayda & Rappaport 1968).

This approach has been very successful in generating detailed descriptions of food producing systems (Anderson 1973, Kemp 1971, Netting 1981), some of which we will draw upon more closely in the next section. In addition to that, it has raised the envy of colleagues by successfully presenting solutions to apparent riddles of bizarre habits and thereby attracting a lot of public attention (Harris 1966, 1977). To illustrate the method we will briefly report on Harner's (1977) famous analysis of Aztec cannibalism.

Pre-Conquest Mexicans were practising human sacrifices in unprecedented numbers. A number commonly cited for Aztecs amounted to 20 000 sacrifices/year. According to Harner's explanation, population pressure increased in the Valley of Mexico and wild game supplies were hardly available any more to provide protein for the diet. Carbohydrates could be secured by agricultural intensification; but domesticated animal production was limited by the lack of a suitable herbivore. In the Old World the domestication of herbivorous mammals proceeded apace with the domestication of food plants. In the New World, the ancient hunters had completely eliminated potential herbivorous mammalian domesticates from the Mesoamerican area (in South America still llama and alpaca had survived, and the guinea pig).[15] This made the ecological situation of the Aztecs unique among the world's major civilizations. Large-scale cannibalism, disguised as sacrifice, was the cultural solution to an ecological problem. The estimated ratios of 5-20 sacrificed war-prisoners per year per 100 inhabitants of Tenochtitlan can be looked upon as a significant contribution to protein diet. This practice also helps to understand a political peculiarity: the Aztecs always withdrew from conquered territories and did not seize them in the Old World fashion. Asked by Cortez, Moctezuma explained this was done so that his people could continue to obtain captives for sacrifice nearby (Harner 1977, 130).

This is a clear example of a metabolic argument. Under certain environmental conditions (that have, at least in part, been produced by previous human cultures) the metabolic needs of a population translate themselves into specific cultural practices. These practices in fact do serve human metabolism. What is not discussed by Harner, though, is the overall ecological efficiency of these practices. Presumably it is not high: humans are not good at converting energy, and, even if mainly raised on a herbivorous diet, will not use the available yield of the land very efficiently. On the other hand, however, these practices result in a certain control of population. This analysis has stood quite uncontested: Hicks (1979) objects only to a minor argument within Harner's theory, and even Orlove (1980, 243), who does not hide his dislike for functionalist interpretations, cites no sources that would substantively criticize Harner's line of reasoning.

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[15] Crosby (1986) used the availability of domesticated herbivore as one of the most important factors explaining the capability of Europeans to conquer the New World.

There certainly are some theoretical and methodological problems in this approach which need to be discussed in greater detail. They entail the difficulty to specify a unit of analysis: a local population? A culture? This is related to the difficulty of specifying the process of change, and to the difficulty of locating inter-cultural (or inter-society-) interactions in this framework. These scientific traditions, however, have prepared cultural anthropologists to be among the first social scientists to actively participate in the later discussion of environmental problems of industrial metabolism (see several contributions in Thomas 1956; Kemp 1971, Rappaport 1971).

Metabolism in social geography and geology

In 1955 seventy participants from all over the world and from a great variety of disciplines convened in Princeton, New Jersey, for a remarkable conference: „Man's role in changing the face of the Earth". The conference was financed by the Wenner-Gren Foundation for Anthropological Research and the geographer Carl O.Sauer, the zoologist Marston Bates and the urban planner Lewis Mumford presided the sessions. The papers and discussions were published in a 1200 pages compendium that documents, so I would claim, the world's first interdisciplinary panel on environmental problems of human development, staged by top science.[16]

The title of the conference was paying honours to George Perkins Marsh, who had in 1864 published the book „Man and Nature; or, Physical Geography as Modified by Human Action", and is considered the father of social geography. For Marsh, man was a dynamic force, often irrational in creating a danger to himself by destroying his base of subsistence. The largest chapter of *Man and Nature* is entitled „The Woods", is pleading for the recreation of forests in the mid-latitudes. He was not, as the participants of the 1955-Conference note, concerned about the exhaustion of mineral resources. He looked upon mining rather from an aestethic point of view, considering it „an injury to the earth" (Thomas 1956b, xxix)

The issue of possible exhaustion of mineral resources was taken up by the harvard geologist Nathaniel Shaler in his book „Man and the Earth"(1905). In considering longer timeseries he noted „since the coming of the Iron Age" the consumption of mineral resources having increased to a frightening degree. In 1600 only very few substances (mostly precious stones) had been looked for underground, but now, at the turn to the 20th century, there were several hundred substances from underground sources being used by man, of essential importance being iron and copper. Shaler was concerned with the limits of the resource base.

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[16] Including not one single woman, but equally not one single sociologist (if one does not take Lewis Mumford as such, which he himself in his biography does not), but several economists (among them, for example, Kenneth Boulding), cultural anthropologists and historians.

One might say this shift of focus from Marsh (1864) to Shaler (1905) reflects the change in society's metabolism from an agrarian mode of production (where scarcity of food promotes the extension of agricultural land at the expense of forests) to an industrial one, where vital „nutrients" are drawn from subterrestrial sinks that one day will be exhausted. It reflects it - but it does not reflect upon it.

With the 1956-volume the concern with a limited mineral base for an explosively rising demand of minerals is even more obvious. Such a „materials flow" focus seems to have been strongly supported by wartime concerns and institutions: Ordway (1956, 988) quotes data from a 1952-report of the „President's Materials Policy Commission" worrying about the „soaring demand" for materials.[17] The depletion of national resources is becomes part of a global concern: „If all the nations of the world should acquire the same standard of living as our own, the resulting world need for materials would be six times present consumption."(988). Based on these considerations, Ordway advances his „theory of the limit of growth", based on two premises: „1. Levels of human living are constantly rising with mounting use of natural resources. 2. Despite technological progress[18] we are spending each year more resource capital than is created. The theory follows: If this cycle continues long enough, basic resources will come into such short supply that rising costs will make their use in additional production unprofitable, industrial expansion will cease, and we shall have reached the limit of growth."(Ordway 1956, 992) McLaughlin, otherwise more optimistic than Ordway, states in the same volume that by 1950 for every major industrial power the consumption of metals and minerals had exceeded the quantity which could be provided from domestic sources (McLaughlin 1956, 860).

Similarly, the 1955 conference experts discuss the chances of severe shortages in future energy supply. Eugene Ayres who speaks about „the age of fossil fuels", and Charles A.Scarlott treating „limitations to energy use" remind of the limits inherent to using given geological stocks. Ayres, elaborating on fossil fuels since the first uses of coal by the Chinese about two thousand years ago, is very sceptical towards geologist's estimates of the earth's reserves, suscepting them to be much larger than current projections, but nevertheless concludes: „In a practical sense, fossil fuels, after this century, will cease to

[17] This report should be an excellent source for reseach into longer time series of materials consumption. Ordway even quotes a number for the „raw-material consumption" of the U.S. in 1950 („2.7 billion tons of materials of all kinds - metallic ores, non-metallic minerals, construction materials and fuels...", 988). Note the number given by Ayres and Kneese 1969 (including agricultural products, but excluding construction materials): 2.4 billion tons. With 151 mio U.S.-inhabitants in 1950, The President's Materials Commission numbers amout to 18 tons of raw materials per inhabitant and year, which is just a little less than Japan's numbers nowadays. (President's Materials Policy Commission (1952), commonly called „the Paley Report").

[18] It is interesting to note that even the idea of materials' consumption growing less than GDP because of increases in efficiency is taken up in the Paley Report: In its projections for 1975 the Paley Report expects U.S. GDP to double compared to 1950, but the materials input neccessary for this only to rise by 50-60% (quoted from Ordway 1956, 989).

exist except as raw materials for chemical synthesis."(Ayres 1956, 380) Scarlott demonstrates the diversification of energy uses and the accompanying rise in demand and then elaborates on a possible future of solar energy utilization (!) and nuclear-fusion as sources of energy.

The bulk of material's flow considerations in the 1955-conference is devoted to the input side of material metabolism, though. The overall systemic consideration that the mobilization of vast amounts of matter from geological sinks (e.g. minerals and fossil energy carriers) into a materially closed system such as the biosphere would change parameters of atmospheric, oceanic and soil chemistry on a global level, does not occur yet. Still, many contributions of this conference document the transformations of local and regional natural environments by human activity, both in history and at present. [19]

The global environmental change issue, then, is taken up by a special issue of „Scientific American" in September 1970, devoted to the „Biosphere". One year later, „Scientific American" edits an issue on energy and socio-economic metabolism in terms of energy (vol.224, no 3, 1971). In 1969 the German geographer Neef explicitly talkes about the „metabolism between society and nature" as a core problem of geography. But this already belongs to the post-1968-cultural revolution of environmentalism we have excluded from this review.

Interlude: Some epistemological suggestions for conceiving society-nature interactions

„The study of the interactions between society and environment comprises the core of environmental sociology" stated Dunlap and Catton in 1979 (251). If human society is conceived of as a purely symbolic system (a system of communication, as Luhmann has it, or a system of cultural meanings as in the tradition of Mead and Schütz), then how does society influence the material world? There must be some touching sphere, some possible *agens* reaching over from the symbolic to the material. On the other hand: with a strictly materialist conception of society, how can one portray the complexity of social processes? Is it possible, for example, to explain, how something like a language, or certain modes of perceiving and organizing these perceptions, evolves? From a materialist perspective it cannot be understood why highly organized symbolic arrangements remain robust over time and why they are not completely randomized by a change in material conditions.

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[19] This tradition is explicitly continued in a further publication, representing the contemporary state of the art of social geography, dating from 1990: „The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years" edited by B.L.Turner II and others.

Given the tools of modern systems theory, there is no need to claim that the symbolic, the „cultural", is something entirely unique to or an exclusive property of human social systems. Processes of self-organization, of information exchange and learning, autopoiesis of some kind, may occur in various complex systems, whether humans are involved or not (see, for various perspectives, Bateson 1972, Maturana 1970, Maturana &Varela 1975, Prigogine & Stenger 1990). In my opinion, these theories have outdated the traditional divide between „materialist" and „idealist" approaches, Plato's schism between the world of matter and the world of ideas.

Modern systems theory may be utilized for properly conceiving of society's metabolism. Following Sieferle (1997), I believe that to do so calls for a dual approach.[20] One needs to be able to describe how symbolic systems may influence material systems, and vice versa. So it makes little sense to put „society" merely on the symbolic side, and „nature" on the material side. It takes a notion of human society that comprises both types of elements, symbolic and material.

In order to escape some of the philosophical strain involved in using distinctions of a contested tradition of two thousand years, involving all the subtleties and misunderstandings accumulated in such a long history, I will „modernize" these conceptions according to contemporary technology and experiment with the terms *hardware* and *software*. Hardware is a structure that is made to function by means of software, given a free flow of energy. Hardware and software can be handled independently - but one without the other does not work. Software usually works on more than one hardware, and vice versa. Both can be developed fairly independently (which presents a business risk to contemporary computer producers they try to minimize). Neither can be said to „rule" or to „dominate" the other: They have to fit together, to understand each other, to communicate well, to be compatible (one is free in choosing a term from the more material, technical side, or from the more symbolic, informational side). One learns about software by making it work on hardware, and one learns about hardware by making software „run" on it. From the system's point of view of software, hardware is just part of the environment, such as, for example, the user. From the system's point of view of hardware, software is environment - hardware has to be constructed in a way that fits into the world of softwares. From the point of view of the user, though, both are complex systems that have to be respected for their own right, and they have to, if anything be achieved at all, cooperate smoothly - as a system of a second order. What is required, then, is

* that hardware and software are well organized systems in themselves,

* that they are linked and fit to one another,

* that there is a flow of free energy entering their linkage to get them moving.

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[20] This also permits a theory of evolution comprising both sides without being reductionist.

So, then, how do hardware and software influence each other? Directly, they make each other work in a specific way. Above that, software can be constructed so that it learns from the pecularities of the hardware, and as a consequence changes incrementally. Hardware cannot „learn“. It gets, if used, old and corroded (a process which can be either enhanced or slowed down by software), will use up its parts after a while, will therefore not only constantly require a supply of energy, but also of materials (that's where material metabolism, beyond energetic metabolism, comes in). Nothing like that will be needed for software. If it is a „learning“ software, it may accumulate too much information and get sturdy and slow as time moves on. But there also could exist an internal mechanism eliminating unneccessary information, or removing it from the path of operation. So software cannot get old and corroded - but it can get outdated by „new“ software, or it can even be rendered useless by a completely new generation of hardware.

It does not make sense to dispute whether either one - hardware or software - „really exists“ (to strike the constructivist string). But they take one another to find out. In the physical world hardware and software can hardly by separated at all. A molecule both contains the matter and the program for operation (it even is the same, a theoretical physicist might say). In the world of living things there is a very important separation: that between an organism and its DNA-sequence. The software may be passed on to other organisms, while the hardware dies.[21] Still there is required a very specific hardware to which the software may be passed on to. In the social world of humans, software may be passed on in almost any fashion. From sounds and mimics to spoken language to books and to electronic media marks a path of increasing independence from the hardware, the human body, and an increasing flexibility of hardware-software links altogether.

Within this picture, culture may be viewed as a highly complex system of software, *software designed to work on the human body.* The human body, of course, is simultaneously run by other software, natural software (genes), and both kinds of software have to have a certain compatibility with one another - which is far from determination.

For the purposes of environmental sociology, then, but probably for many other purposes as well, it makes sense to conceive of human social systems as systems of second order, comprising the system of culture (or software) as its symbolic, and a certain human population, that is a certain number of somehow interconnected human bodies, as its material compartment. And for the purpose of societal metabolism, as we will argue further down, it also makes sense to consider material artefacts and domestic animals als material compartments of human social systems, as a kind of „drag-ins“ from nature.

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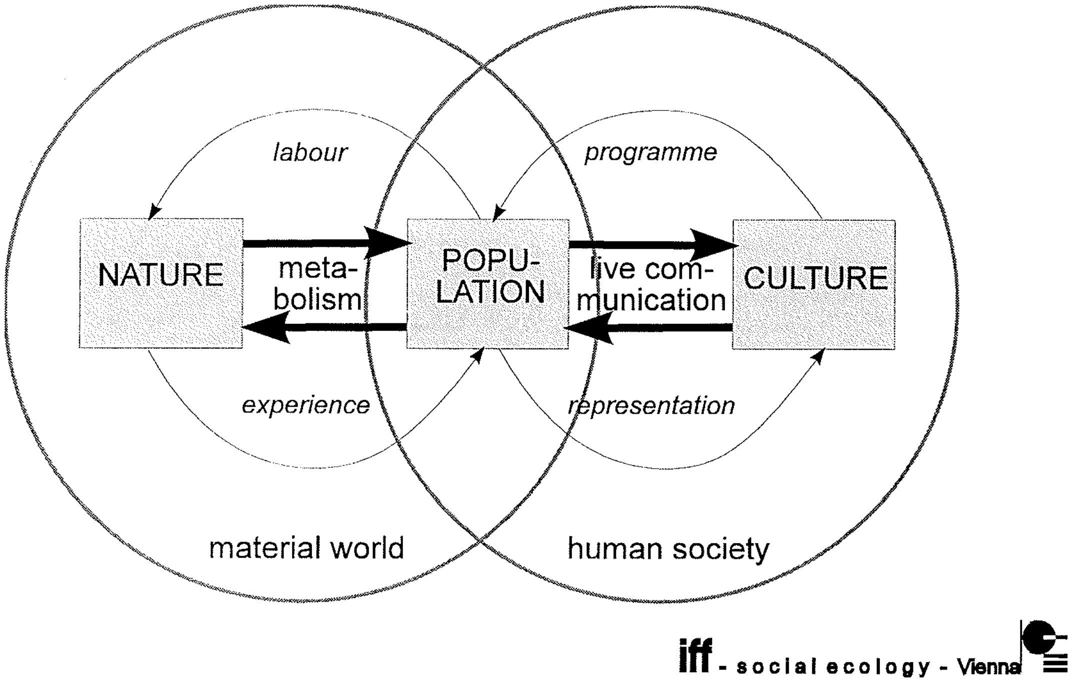
[21] In commenting upon this paper, R.P.Sieferle made me aware that more specifically one would have to distinguish between hardware that serves as a carrier of information (a floppy disk, for example, or a genome), and hardware that performs the physical functions (such as a robot, or a body).

Figure 1

Interaction model society - nature



Source: Sieferle lectures 1995, „metabolism" and „live communication" added MFK

Sieferle himself stresses that this is still a tentative model. However, it permits to establish a systematic link between what he calls the „symbolic" system of culture and „material" systems of nature: the population. The population relates to the system of culture by receiving its „program" (or software, as we chose to call it above) and by generating representations of the material world that are fed back to the cultural system. On the other hand, it relates to the material world by means of „labour" (physical expenditure of energy in an intentionally designed fashion) and by the „experience" it makes in the material world. Both „labour" and „experience" are, of course, highly structured symbolically, but they also contain material elements. By the terms introduced above one might say they consist of hardware guided by cultural software.

How, then, does metabolism fit into this model? If we think of it as a process of material and energetic reproduction of the material compartments of society, this certainly must comprise more than the energy and matter processed by the human bodies that make up the population. What it comprises has to be properly defined and should if possible fulfil the following prerequisites:

1. It should be specifiable in a consistent manner for various social systems, whether they are ordered hierarchically or horizontally. If this is the case, it would alleviate the problems associated with choosing the proper level and unit of analysis.

2. It should be consistent with the physical law of constancy of energy and matter, or, put differently, have consistent equations between input, output and change of stocks in material and energetic terms.

3. It should make sense in terms of social meaning and activities but be sufficiently abstract to apply to various social systems (both historically as with regard to hierarchical level).

Various operational definitions have been advanced in the course of analyses of „industrial metabolism“ more recently, but they hardly comply with the above standards. In a book to be published in German (Fischer-Kowalski et al. 1997), I have recently suggested to consider as part of the metabolism of a social system *those material and energetic flows that sustain the material compartments of the system.* This seems quite in accordance with the biological resp. biochemical definitions of the term. But what, then, are the material compartments of a social system? I have made the following proposal: Material compartments of a social system are those *physical entities that are continually reproduced by the labour expanded in this system.* For the level of a society as a whole this encompasses

- the population, i.e. the human organisms that „belong“ to that system,

- those physical objects that anthropologists term artefacts: buildings, machines, goods in use. (Mind that this does not comprise all man-made objects, though: only those that are still kept in a certain condition by the application of human labour. Artefacts to which this does not apply, are wastes, left-overs on their way to renaturalization.)

- those animal organisms that are „kept“ by humans, fed and bred (livestock and domestic animals)

- finally possibly those plant organisms that are „kept“ by humans - but note that the word „kept“ cannot be properly applied to plants, since it is much harder to distinguish between plants „kept“ and those not „kept“ (Fischer-Kowalski 1997, 62ff).

Typically, social systems do define and reproduce their boundaries in terms of their compartments: they distinguish between what „belongs“ to them and what does not. An important definition of this kind is „property“: property may be regarded as a symbolically defined relation between a social[22] „subject“ and an (not neccessarily but frequently material) „object“. So in operationally defining the material compartments of social systems one can (and should) usually draw upon the system's self-definitions.[23]

[22] When using the term „social“ I always mean both material and symbolic, thoroughly interlinked

[23] Admittedly, the distinction between material system-compartments and the environment will remain fuzzy. Consider a heap of sand in front of a house: First it is transported there for some purpose. Then it is left for the rain to be swept away. Subsequently, a new purpose arises, and the sand gets built into the floor of the terrace. Or maybe just the neighbour's kid is digging into it with his shovel, stirring up an argument of „property“ vs. "leftovers“.

When trying to establish the energetic and material flows required for sustaining the material compartments of social systems, the self-definitions of this system are only of limited support, though. Systems usually are only aware of those flows they spend effort upon, and not of those flows that seem to occur „naturally“. But if one does not want to violate condition 2 (input-output-equality), one has to consider, for example, not only the food a hen is fed but also the oxygen it requires to digest this food, and not only the manure it deposits but also the carbondioxide it exhales. So, once the compartments are established by utilizing social definitions, the material and energetic flows have to be and can be analyzed with the tools of natural science.

The state of the art: Socio-economic metabolism as a conceptual response to the „spaceship earth“

In the late sixties, when it became culturally possible, once again, to take a critical view at economic growth and consider its environmental side-effects, the stage was set for a new twist in looking upon socio-economic[24] metabolism. Up to this point metabolism had mainly come up in various discourses by way of arguments claiming that natural forces and physical processes did, indeed, matter for the organization and development of society, and that it would be reasonable, therefore, to attribute to them some causal significance for *faits sociaux*. The mainstream of social science dealing with modern industrial society - whether it is economics, sociology or political science - had not cared about this issue at all. In the mid-sixties this started to change, and - apparently originating from the U.S. - a set of new approaches developed, often triggered by natural scientists, and subsequently further developed, typically in cooperation with social scientists. In these approaches the material and energetic flows between societies (or economies) and their natural environment became a major issue - governed by the worry that a „cowboy economy“ might not be compatible with „Spaceship Earth“(Boulding 1966). The common picture of cultural evolution as eternal progress started to give way to a picture of industrial economic growth as a process which possibly implied the fatal devastation of human life. This must be considered as quite a basic change in worldviews, and it took hold of a wide range of intellectuals across many disciplines. It promoted, as one might say, something like a rebirth of of the paradigm of socio-economic metabolism, applied to industrial societies.

[24] In talking about industrial society, one has to take into account its high degree of functional differentiation, with the economy mainly responsible for handling material and energetic flows. It might contribute to common understanding, therefore, to talk about „socio-economic“ systems - incidentally, this would also help to evade another terminological problem: „social systems“ are not confined to humans. Thus, in order to be precise, one would mostly need to refer to „human social systems“, which is probably irritating for social scientists and not precise from the point of view of systems theory, either.

Achievements of the pioneers in the late sixties

„The metabolic requirements of a city can be defined as the materials and commodities needed to sustain the city's inhabitants at home, at work and at play. (...) The metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed of with a minimum of nuisance and hazard." (Wolman 1965:179) These lines served as the introduction to the first attempt to conceptualize and operationalize the metabolism of industrial society, i.e. the case study of a model U.S. city of one million inhabitants, by the water-supply specialist (and participant of the 1955-conference on „Man's Role in Changing the Face of the Earth") Abel Wolman in 1965. He is well aware of the fact that water is the input needed in the highest quantities by far, but also offers estimates for food and fossil energy inputs, as well as (selected) outputs such as refuse and air pollutants. His argument is mainly directed at problems he foresees with respect to providing an adequate water supply for American megacities.

The economist Kenneth Boulding had also been a participant in the 1955-conference. In „The Economics of the Coming Spaceship Earth" With reference to Bertalanffy (1952), Boulding (1966) briefly outlines an impending change from what he calls a „cowboy economy" to a „spaceman economy". The present world economy, according to this view, is an open system with regard to energy, matter and information („econosphere"). There is a „total capital stock, i.e. the set of all objects, people, organizations and so on" that have inputs and outputs. Objects pass from the noneconomic to the economic set in the process of production, and objects pass out of the economic set „as their value becomes zero" (Boulding 1966:5). „Thus we see the econosphere as a material process." This similarly can be described from an energetic point of view. In the „cowboy economy", throughput is at least a plausible measure of the success of the economy. „By contrast, in the spaceman economy, throughput is by no means a desideratum, and is indeed to be regarded as something to be minimized rather than maximized. The essential measure of the success of the economy its not production and consumption at all, but the nature, extent, quality and complexity of the total capital stock, including in this the state of the human bodies and minds."(Boulding 1966:9) Here we find one of the first systematic considerations of the material compartments of - as I would say - society, or what Boulding calls the econosphere, visualized as an input-output system within the biosphere. Boulding does not, as occasionally happens with systems approaches, confound the economy or society with an ecosystem.[25]

In 1969 Bob Ayres, a physicist, and Allen Kneese, an economist, basically presented the full programme of what - much later, in the nineties - was carried out as material flow

[25] Sachs (1993) has drawn attention to human technical grandiosity implied in the image of the „Spaceship Earth", as if it were to be steered and maintained by humans. Later analysts of socio-economic metabolism, in contrast, propagated the humbler idea of society downsizing its own material and energetic turnover.

analyses of national economies.[26] Their core argument is an economic one: The economy heavily draws upon priceless environmental goods such as air and water - goods that are becoming increasingly scarce in highly developed countries - , and this precludes Pareto-optimal allocations in markets at the expense of those free common goods. They conclude with a formal general equilibrium model to take care of these externalities. In the first part of the paper the authors give an outline of the problem and present a first material flow analysis for the United States 1963-1965 (see Table 2). They claim „that the common failure (of economics) (...) may result from viewing the production and consumption processes in a manner that is somewhat at variance with the fundamental law of the conservation of mass."(Ayres & Kneese 1969:283) There must occur, they argue, uncompensated externalities unless either 1/ All inputs of the production process are fully converted into outputs, with no unwanted residuals along the way (or else they all be stored on the producers' premises), and 2/ all final outputs (commodities) are utterly destroyed, made to disappear, in the process of consumption, or 3/ property rights are so arranged that all relevant environmental attributes are in private ownership and these rights are exchanged in competitive markets. „Neither of these conditions can be expected to hold."(283) „Nature does not permit the destruction of matter except by annihilation with anti-matter, and the means of disposal of unwanted residuals which maximizes the internal return of decentralized decision units is by discharge to the environment, principally watercourses and the atmosphere. Water and air are traditionally free goods in economics. But in reality,... they are common property resources of great and increasing value. (...) Moreover, (...) technological means for processing or purifying one or another type of waste discharge do not destroy the residuals but only alter their form. (...) Thus, (...) recycle of materials into productive uses or discharge into an alternative medium are the only general options (...)"(283).

„Almost all of standard economic theory is in reality concerned with services. Material objects are merely vehicles which carry some of these services... Yet we (the economists) persist in referring to the „final consumption" of goods as though material objects ... somehow disappeared into the void....Of course, residuals from both the production and consumption processes remain and they usually render disservices ...rather than services."(284) Thus they propose to „view environmental pollution and its control as a *materials balance problem* for the entire economy." (emphasis added, 284) "In an economy which is closed (no imports or exports) and where there is no net accumulation of stocks (plant, equipment, ...or residential buildings), the amount of residuals inserted into the natural environment must be approximately equal to the weight of basic fuels, food, and raw materials entering the processing and production system, plus oxygen taken from the atmosphere."(284)

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[26] Their article is based upon a report prepared for the US-Congress by a Joint Economic Committee and published in a volume of Federal Programs in 1968 (see Ayres and Kneese 1968).

Within these few paragraphs, almost all chords of the future debate are strung. The model of socio-economic metabolism presented (a term that is not used in the contribution) owes more to physics than to ecology. For an organism, it is obvious that some residues have to be discharged into the environment. In population ecology, it is the efficiency of energetic conversion that would be considered - not the recycling of materials. This clearly would be the task of the ecosystem: In the ecosystem it is the „division of labor“ of different species that would take care of materials recycling, and never the members of one species only. From the point of view of ecosystems theory, therefore, the idea of residues as a „disservice“ to the population discharging them would seem alien to the common concept of nutrient cycles and cataractic use of energy in an ecosystem.[27] Ayres and Kneese then proceed to present an overview of the „weight of basic materials production“ in the United States. They consider only what they call *„active inputs“*(28). The criterion they apply is whether a material undergoes chemical change in the process of being used. Thus, they exclude construction materials (stone, sand, gravel and other minerals used for structural purposes), as well as gangue and mine tailings. They consider their use as more or less „tantamount to physically moving them from one location to the other“(28). If these materials were to be included, the authors see no logical reason to exclude material shifted in harbour dredging or plowing[28] - „a line must be drawn somewhere“.

This is a way to admit a problem not really tackled in this article: *Where is the borderline between the economy, resp. the social system, and nature?* As a consequence, it is hard to handle another problem with the neccessary clarity of distinction: What is the status of livestock in a material balance? The 1969 publication treats „crops“ (with the exclusion of crops used to feed livestock) and „livestock and dairy“ as basic material input. Thus, Ayres & Kneese partially, and logically, externalize animal husbandry from the economy: Livestock is not considered a „product“ of farming, but an input from nature. In their revised version of 1974, they do include crops used for feeding livestock, which leads to double-counting: Those crops used to feed livestock enter the calculation both in a primary manner, as fodder, and in a secondary manner, as milk or, respectively, meat.

[27] I think Ayres & Kneese do indeed interpret a qualitative problem as a quantitative one. As long as societal metabolism remains a *basal metabolism*, i.e. draws its inputs from the actual cycles within the biosphere, it may suffer from problems of resource scarcity. It may not, however, suffer from problems of pollution (except for some possible forms of local pollution as a consequence of spatial concentration). It is only when it becomes an *extended metabolism*, mobilizing materials stored for billions of years from geological sinks, that it may temporarily overcome problems of resource scarcity, but simultaneously generate problems deriving from residues (more elaborate in Fischer-Kowalski & Haberl 1996).

28 A problem once again discussed extensively by Schmidt-Bleek and colleagues, [# vorgeschlagene Einarbeitung von Bringezu's Kommentar: who have meanwhile developed a method that includes any natural material moved by man in the material flow account. The former categories of „translocated materials“ - not to be included in material turnover (Schütz & Bringezu 1993), but accounted for by way of „material rucksacks“ of goods and services (Schmidt-Bleek 1993, 1994); or even in the national material turnover balance(Bringezu et al.1994, Bringezu 1995) - are still being counted, but are subsumed under other input categories. The only systematic categories used are Inputs and Outputs.

Nevertheless, the total input is underestimated: Since this livestock does not only feed on crops, but is also grazing, the (considerable) amounts consumed in grazing are missing. We will see below the quantitative differences entailed in this fuzziness. But this does not in the least diminish the outstanding pioneer qualities of this paper.[29]

Ayres' and Kneese's *„active inputs"* also do not encompass air and water. Whereas, in the 1969 publication, the input of oxygen is no more than mentioned, in the successive publication (Kneese et al.1974) it is considered in an extensive footnote: The category now does include the oxygen required for human and livestock respiration, as well as that required for technical combustion which amounts almost to the tenfold of all respiration (53). In both publications water is not discussed as an input quantity, but only as part of the problem of pollution.

Whereas the inputs from the environment to the economy are listed in some detail, the outputs to the environment (in the sense of residuals) are only treated in a sweeping manner. Nevertheless, all the problems that have marked the following decades of emission- and waste policies - problems that still have not been properly resolved yet - are represented in all clarity: It is spelled out clearly that there is a primary interdependency among all waste streams that evades treatment by separate media. The authors of this article are even as prophetic as recognizing that there is one stream of waste that is non-toxic and, hence, not interesting for emission regulation - carbon dioxide. They anticipate correctly that carbon dioxide, for its sheer quantity, might become a major problem (changing the climate). Finally, they are able to see that a reduction of residuals can only be achieved via a reduction of inputs. All these are the core insights of the materials balance approach these authors may be said to have „invented". And although one may suspect that the formalized link to an economic model of externalities generated at once almost too much information packed in one article to secure an effect, this contribution became a starter to a research tradition capable of portraying the material and energetic metabolism of advanced industrial economies. It was not „man" any more that was materially and energetically linked to nature, but a complex and well defined social system: „The dollar flow governs and is governed by a combined flow of materials and services (value added)" (Kneese et al.1974:54).

Judged by the standards of later European data, the empirical results rendered by these pioneer studies appear to be in the order of magnitude to be expected. Of course the results depend upon the definition of the social system, its compartments and the relevant material flows (see first line of „totals" in Table 1: The per capita values differ by factor 20); Once the definitions are harmonized, however, the results obtained seem quite in accordance with one another (see adjusted per capita volumes in the last line of Table 1).

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[29] It is interesting to note that a quarter of a century later this very same flaw can still be observed in the official statistical report on the material balance of Japan (see Environment Agency 1992, 1993). For the Japanese metabolism it makes less of a difference, though, since they mainly import their livestock and diary products.

Table 1

The structure of industrial metabolism[30] - pioneer studies and „state of the art" compared (annual material consumption[31] in tons, overall and per capita)

	U.S.national consumption 1965 (Kneese et al. 1974)		U.S.city 1965 (Wolman 1965)	German Federal Republic 1970 (Stat.Bundesamt 1995)	
	mio tons/y	mio tons/y*c	tons/y*c	mio tons/y	tons/y*c
water			207.3[32]	33572	568.9
oxygen	3100[33]	15,5		559[34]	9.3
food & fodder	389.5	2.0	1.8	140	2.3
other biomass	218[35]	1.1		30	.5
fossil fuels	1448	7.2	8.6	374	5.8
construction materials				591	9.5
other materials	585[36]	2.9		74	1.2
total	5540.5	28.7	217.7	35340	597.5
adjusted total [37]		**20.8**	**22.6**		**19.3**

This even holds true for an early publication from the USSR: Streibel (1990) refers to a study published in Moscow in 1974 by Gofman et al. that describes the overall material metabolism of the national economy of the Soviet Union and presents a highly aggregated quantitative model for the flows to and from the biosphere and between various parts of the economy. Since the original source is not available, it is hard to tell how thorough this analysis was and what kind of definitions it applied (for example: Water is included in the material flows, but how about oxygen?). It is interesting to note, however, that the overall amount of material extracted from the environment (amounting to 300 billion tons) matches with the data from Ayres and Kneese 1969: Suppose the construction materials are included in the Moscow data, the American 2.5 million of raw material input would have to be doubled to 5.0. Raw materials do amount to about 5% of total material

[30] The term „industrial metabolism" was coined quite recently by the comprehensive book edited by Ayres & Simonis in1994. This book raised the old issues again on a well-received international level.

[31] National production plus imports minus exports

[32] Obviously water for industrial energy generation (cooling) not included

[33] Atmospheric oxygen only: 2.74 bio t combustion, .3 bio t animal respiration, .06 bio t human respiration

[34] Atmospheric oxygen for combustion only (without animal or human respiration)

[35] Forestry products on a 85% dry weight basis

[36] „Other minerals"

[37] Without oxygen and water; construction materials assumed according to German per capita values

throughput. So out of the 300 billion tons there should be approximately 15 million tons of raw materials, if air was not included in the total, or 12 million tons if it was. Thus the amount of material throughput in the Soviet Union of the seventies would have been 2-3 times as large as that of the United States. Considering, apart from possible differences in material efficiency, that one of the two systems tried to downplay its wastes, and the other tried to exaggerate its production, the result is not altogether out of range.

We may conclude, therefore, that the pioneer studies of overall material metabolism not only set up an appropriate conceptual framework, but also arrived at reasonable empirical results. Considering this fact, it is amazing that it took about another twenty years until this paradigm and methodology became widely recognized as a useful tool.

Outlining the paradigm: An overview of the literature

I will now try to give an overview of the more recent literature. Before doing so, I have to explain the process of selection. The following decisions have been taken:

1. Whereas, in the preceding sections, I have tried to unveil the „roots and traces" of some contemporary research strategies over a wide field of disciplines, I now have to narrow down to some more closely related approaches and exclude others. *Firstly,* I confine myself to systemic rather than linear approaches, i.e. to research that focuses on some social system and not just on a group of processes. Readers looking for publications on emissions and emission reduction of cars, for example (which technically in fact *is* a metabolic problem of societies) will not find them here. *Second,* I confine myself to studies that explicitly relate to social and economic variables. *Third,* I have given preferential treatment to publications on material rather than on energy flows. The *energetic* metabolism of industrial societies has seen a lot of research, directed at technological alternatives and energy-saving strategies, that will not be represented in this review.[38] Similarly I have hardly touched upon the metabolism of industrial societies in *monetary* terms. Obviously, economic input-output-analysis teaches a lot about societal metabolism, and there exist various approaches to relate this to environmental concerns. These approaches will not be reviewed here.[39]

2. In screening the literature, it became apparent there had been several „waves" of related research, with later efforts typically unaware of, or not taking notice of previous publications. This was to be expected in view of their scattered nature, both in terms of

[38] Cf., however, the review done by Rosa et al.1988; an excellent diachronic perspective is provided by Sieferle 1982.

[39] This might generate a somewhat skewed picture of relevance. The criticism of economic growth by economists (e.g.Boulding 1966, Daly 1973) as well as the application of input-output-models to physical exchanges between the national economy and its natural environment (e.g. Leontief 1970, Duchin 1989, Duchin 1989, 1992) have played a major role in moulding the paradigm of „industrial metabolism". See also Martinez-Alier & Schlüpmann 1994.

the disciplines and the media of publication involved, but it did not ease my task as a reviewer. Beyond some approaches in the early postwar years (which, in part, have been reviewed in the preceding paragraphs), a major „first wave" of research surged in the late sixties. This stimulating wave of research in ecology had a lot of conceptual power to mold issues in the light of culturally new environmental concerns, and mainly originated from the United States where environmental issues also politically were most advanced. I will refer to first wave publications more extensively as they set milestones for subsequent research strategies. The „second wave" which I am going to review is very recent: It dates from the early nineties and represents the contemporary state of the art.[40] This second wave is largely European of origin, with a lot of publications from German-speaking or Scandinavian countries and from the Netherlands.[41]

3. As far as possible, I will refer to very comprehensive publications on the one hand, to original research reports (in their published rather than their „report"-versions) on the other hand. I will not refer to repeatedly updated versions of one and the same research publications containing but minor revisions, unless they are better accessible in terms of language by being written in English. Papers not presenting any empirical results but contributing to conceptual clarifications will be mentioned in the course of the discussion, but will not be included in Table 2.

In presenting the overview of literature in Table 2, I am going to draw some basic distinctions I will briefly explain. The reader should be aware, however, that they do not only appear somewhat arbitrary at times (several pieces of research might be placed within more than one „cell" of this framework), but also group together highly heterogenous approaches within one and the same category that would have to be elaborated and expanded upon in more detail.

Frame of reference: socio-economic system / ecosystem

There are basically two ways of handling anthropogenic material and energetic flows: It is possible, first, to focus on some social or *socio-economic system as a unit of analysis*, treating it like an organism or some sophisticated machine. Second, one may look at such a system from an „environmental" perspective corresponding to the *ecosystem perspective* in biology. In the second case, one looks at the larger system within which the socio-economic system operates, and relates inputs and outputs to the stocks and flows within the larger system.

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[40] The years in between - i.e. the late seventies and the eighties - have generated a large body of specialized literature on pollutants, but seem to have missed some of the systemic „bite" then regenerated in the nineties on a larger scale. Thus, the time distribution of the citations is not simply a bias resulting from unequal sampling, but mirrors a change in research focus.

[41] In such a dynamic field as the one presented here one may easily overlook important recent research. Since efforts are made within the European Union to support continuous mutual exchange in this field of research, chances were better that I would know of related European rather than U.S. American efforts. As far as Japanese publications in English go, they should be included, as well as those from Australia.

Whereas the first type of approach, the socio-economic system perspective, developed as a social science frame of analysis, the second type, the ecosystem perspective, is rather a natural science enterprise. Both of them, however, are concerned with the fate of social systems of human beings and the sustainability of their metabolism - within different frames of reference. These approaches, of course, can be linked, and suggest themselves to be linked by *mutual feedbacks.* This may be achieved within an overall formal model trying to simulate interactions between socio-economic and natural systems, or as a combination of analytic and normative modelling techniques which are frequently used in more recent (usually national) projections of „sustainable development". (For examples see Table 2).

Hierarchical level of reference system: global / national / regional / functional

Socio-economic systems can be looked upon at different hierarchical resp. functional levels. One may choose to look at the *global* anthroposphere - involving mankind in the global economy - as a virulent component of the biosphere, corresponding to the geo-biosphere for the ecosystem perspective; or one may choose to look at a *nation* state or a *national* economy, at some *regional* unit (such as a city), or at some *functional* unit (such as a firm, a household, or an economic sector).

It is important, however, to determine the extent to which the unit chosen may be properly looked upon as a social system, i.e. to what extent it is integrated by social and economic organization. The less this is the case, the more difficult it becomes to consistently draw a borderline between the system and its environment. This problem is intimately linked to another distinction to be discussed later, viz the compartments of the system. From the point of view of ecosystems analysis, the further one moves down the hierarchical levels of organization, the more difficult does it become to find an appropriate ecosystem in which the socio-economic system can be thought of as being embedded: The side-effects of the metabolism of a particular social system such as a city, or an economic sector, are usually neither confined to a certain territory, nor to a specific ecosystem.

Flows under consideration: energy / material(s) / chemical substances

In analyzing the metabolism of a socio-economic system, or the material flows between this system and its environment, one may look at its *total* turnover in terms of *matter* or in terms of *energy* (or both), or one may select certain flows of materials or chemical substances. Some studies look at the role of certain *input-materials* in the metabolic process (for example: metals and minerals, or energy carriers) and try to determine their uses as well as their pathways through the system in question. Other studies look at *output materials* and try to determine how the system in question generates them (e.g.carbon dioxide, ozone depleting substances, or phosphates).

Table 2

**Analyses of the metabolism of industrial society by research paradigm.
An overview of the literature 1966-1996**

hierarch.level	focus on socio-economic system	focus on ecosystem or on feedback-loops
global	Forrester 1961, Starr 1971, Malenbaum 1978, Jänicke et al.1989, Larson et al.1991, Baccini & Brunner 1991, Jänicke et al.1993, Rogich et al.1993b, Ausubel & Langford 1994	Bolin 1970, Brown H.1970, Brown L. 1970, Cloud & Gibor 1970, Deeney 1970, Delwiche 1970, Oort 1970, Penman 1970, Singer 1970, Woodwell 1970, Meadows et al.1972, Lieth & Wittacker 1975, Vitousek et al.1986, Turner et al.1990, Meadows et al.1992, Wright 1990, Gleick 1993, Kates 1994, Munasinghe & Shearer 1995
national	*overall material metabolism*	
	Ayres & Kneese 1969, Kneese & Ayres 1974, Gofman et al.1974, Auby 1985, Steurer 1992, Environment Agency Japan 1992, 1993, 1994, Rogich et al. 1993a, Schütz & Bringezu 1993, Fischer-Kowalski et al.1994, Steurer 1994, Kuhn et al.1994, Statistisches Bundesamt 1995, Konijin et al.1995, Wernick & Ausubel 1995, Bringezu et al.1996, Haberl 1996, Hüttler et al. 1997a,b	
	selected materials / substances	
	Cook 1971, Herman et al.1989, Daniels 1992, Gerhold 1992, 1994, Binswanger 1993, Kranendonk & Bringezu 1993, Lauber et al.1993, Liedke 1993, , Stiller 1993, Ayres & Ayres 1994, Ayres et al.1994, Husar 1994, Kleijn et al.1994, Kluge et al.1994, Moore & Tu 1995, Lohm et al.1994, Palm et al 1994, Bressers 1995, Lundqvist 1995, Manstein et al.1995, Merten et al.1995, Mez 1995, Nickel & Liedke 1995, Russel & Millstone 1995, Weidner 1995, Picton 1996	Opschoor 1985, Weterings & Opschoor 1992, Buitenkamp et al. 1993, Muhkherjee 1993a,b, Kosz 1994, Muhkherjee 1994, Bund-Misereor 1995, Enquete-Kommission 1995, Morigushi 1995, Haberl 1997a, Hüttler & Payer 1997
regional unit	Wolman 1965, Baccini & Brunner 1991, Baccini et al.1993, Brunner et al.1994, Voet et al.1994	Stigliani & Anderberg 1994, Spangenberg / Friends of the Earth 1995
economic unit	Thompson 1979, Nappi 1989, Fischer-Kowalski et al.1994, Behrensmeier & Bringezu 1995, Kisser & Kirschten 1995	
long-range perspective	Kemp 1971, Rappaport 1971, Starr 1971, Netting 1981, Kabo 1985, Cane 1987, Layton et al.1991, Fischer-Kowalski & Haberl 1993, Netting 1993, Ayres & Ayres 1994, Ayres et al.1994, Fischer-Kowalski & Haberl 1997a,c	Boserup 1965, Loucks 1977, Cooter 1978, Gliessmann 1978, Sieferle 1982, Altieri 1989, Vasey 1992, Kates 1994, Sieferle & Müller-Herold 1996

The same distinctions apply to the ecosystem, resp. the feedback frame of analysis: Certain *system inputs* may be related to *resource availability* in the reference ecosystem. Typical research topics in this tradition include comparisons of the production rates of certain resources within the reference ecosystem to their „rates of consumption" on behalf of a particular social system (e.g. the proportion of net primary production of plants, or NPP, which is is appropriated by a certain nation state). In the case of so called „non-renewables", i.e. resources taken from long-term geological sinks, the relation of stocks to rates of extraction may be analyzed, or the rates of devaluation of stocks (through declining concentrations of some resources, for example). Similarly, one may concentrate on *system outputs* (emissions and wastes) and relate them to absorption- or storage capacities within ecosystems, or simulate the ecosystem's reactions to these outputs (such as global warming). Other authors compare the *total of flows of certain substances* mobilized by a social system to the total of these flows in a reference natural system. (see table 2).

Time horizon: contemporary point in time / time series / long-range historical perspective

The time horizon of the research reviewed will not be fully represented in table 2. Here I just distinguish as a seperate group those studies that perform or permit a comparison between the metabolism of industrial socio-economic systems to other types (other social formations, or modes of production, or historical systems). This is both of conceptual and of practical interest: What happens, if all mankind attempts to change its traditional, current metabolism to an industrial metabolism? Such a question can be approached both from an historical perspective, comparing over long time periods, and by a cultural anthropological perspective, that portrays traditional (pre-industrial) modes of living of contemporary communities.

Research on the global level

On the global level it is relatively easy to define the ecosystem corresponding to the „anthroposphere": It is, of course, the geo-biosphere of our planet. Both columns of Table 2 which refer to the different frames of analysis, contain several entries of research publications concerned with global problems. With regard to the focus on socio-economic systems, „globalness" is, of course hard to substantiate empirically.[42] The number of people making up the global population is known, as well as a great number of economic parameters: These, however, exist largely in the form of data in monetary terms, occasionally in energetic terms as well, but hardly in terms of materials weight. The entries in this segment of the table refer, therefore, either to comparative approaches dealing with the amounts of certain selected materials produced or consumed (such as Baccini & Brunner 1991, Jänicke et al. 1993, Rogich et al.1993b), or to technological

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[42] For the emergence of the so-called Modern World System, cf., *inter alia,* Wallerstein (1974,1980,1989).

trend analyses (Ausubel & Langford 1994, Larson et al.1986), or to very general projections with variables generated by models rather than established empirically (Forrester 1961).

This limitation also applies to the entries in the second column of Table 2 such as the classic „Club of Rome" reports by Meadows et.al.(1972, and again in 1992). Their model simulating feedback processes between a growing socio-economic world system and its natural environment operates theoretically on the level of material amounts (of agricultural and industrial production, for example). The data that entered the models, however, were monetary data which - for all that is known so far - are different in their dynamics. The famous „limits to growth"-models, therefore, were very influential in framing a certain world-view and in supporting a systemic perspective. They were not that influential when it came to the development of empirical research strategies concerned with socio-economic metabolism - mainly for lack of appropriate data, and for the lack of emphasis on the need to generate them in the first place.[43]

The ecosystem perspective on the global level (see column 2 of Table 2) was strongly promoted by the September 1970 issue of *Scientific American*. The whole issue, under the heading „Biosphere", was devoted to material and energetic cycles (carbon: Bolin 1970, oxygen: Cloud & Gibor 1970, nitrogen: Delwiche 1970, mineral cycles: Deevey 1970, water: Penman 1970, plant energy: Woodwell 1970), placing material and energetic socio-economic processes within this framework (materials production: Brown H.1970, food: Brown L.1970, energy: Singer 1970). Other entries in this cell refer to a research tradition relating overall plant energy storage (NPP) to its human appropriation (Lieth & Wittacker 1975, Vitousek 1986, Wright 1990, Munasinghe & Shearer 1995), and similarly for water-cycles (Gleick 1993).

research on the national level

The national level seems to have been the most productive approach in terms of conceptual development and empirical research. On this level, the socio-economic system can be analyzed by means of a lot of data provided by a host of institutions concerned with national economic accounting. The calculation of an *overall material metabolism* of a national economy of course is methodologically quite demanding. It requires, as a data basis, economic statistics for all materials not only in monetary terms, but also in terms of weight (analogous to the more common energy statistics in joule). Meanwhile, there are two countries that have incorporated such overall materials flow statistics on a regular basis into their standard public statistics (Germany and Japan), and some other countries are on the verge of doing so (Austria, Netherlands, Sweden). For the U.S., there exists a

[43] At IIASA in Laxenburg, Austria - the International Institute of Applied Systems Analysis, one of the high profile research centers for global studies - two of the „founding fathers" of materials flow analysis, B.Ayres and F.Schmidt-Bleek, tried to establish a research focus for years, in vain. (personal communication)

fairly comprehensive overview of material metabolism for 1990 (Rogich et al.1993, Wernick & Ausubel 1995). The continuation of this tradition, let alone the incorporation in national statistics, is seriously threatened by the dissolution of the U.S. Bureau of Mines and several of the statistics it used to produce (Wernick & Ausubel 1995). This total of materials flows of a national economy is particularly important as a parameter that can be presented in time series and related to economic performance in monetary terms. For the total of materials flows of a national economy, it is, however, practically impossible to establish a corresponding „ecosystem". The overall material or energetic metabolism of a nation state, i.e. the national economy of an industrial country, is embedded in the geo-biosphere of the whole planet as its natural environment. Accordingly, some normative assumptions are required concerning the „share" of the world-wide material flows held by a particular national economy, and this can only be established for selected materials. Therefore the corresponding cell in column 2 of Table 2 is empty.

This is not the case when it comes to selected material or substance flows on the national level. The research on selected material flows links up well with more traditional research approaches of environmental science concerning emissions and wastes (column 1), as well as imissions (column 2); it also ties in well with statistics concerning economic production and consumption, and it often relates to certain national environmental policies of emission control (see, for example, the policy-oriented volume by Jänicke and Weidner 1995, from which several of the entries in column 1 are drawn). Compared to the analysis of overall national material metabolism above, this approach is not as demanding with regard to conceptual as well as data integration. One major field of application of such analyses is the various national programmes of „sustainable development" launched, sometimes, officially, and sometimes on the level of NGOs, as can be seen from column 2 (see Weterings & Opschoor 1992, Milieudefensie 1993, Kosz 1994, Bund-Misereor 1996, Enquete-Kommission 1994). It is somewhat easier for selected material flows to define an ecosystem which is affected by the socio-economic processes, but it is still quite difficult: As a general rule, atmospheric and water systems do not respect national boundaries, and many material flows cannot be confined to territorial parameters. The only major exception is energy stored in plant biomass which can reliably be established for a national territory and related to human consumption (see Haberl 1997b). In the process of defining standards of sustainable development on national levels, however, it may be expected that research efforts in this area will increase further.

research on a regional level

Generally speaking, the advantage of reseach on a regional level is that the region may be chosen in a way which ensures that „natural" boundaries largely coincide with political and economic boundaries, thus allowing for approaches within both frameworks. This may be the case with relatively small regional units (a city, for example, see Wolman 1965, a valley/watershed, see Fields 1993, Stigliani & Anderberg 1994, or a secluded rural area, see Eder et al.1995), or with large units such as Europe as a whole (Voet at al.1994, Friends of the Earth Europe 1995). A typical problem on this level, however, is often the lack of reliable statistical socio-economic data. They often have to be generated by very expensive empirical efforts (e.g.Baccini et al.1993).

research on the level of an economic unit

The units under consideration are: Households (see Thompson 1979), individual firms (not included in this review) or branches of economic activity (Fischer-Kowalski et al.1994, Behrensmeier & Bringezu 1995, Kisser & Kirschten 1995). This seems to be a promising area of research, since it can easily be linked to industrial policies and economic forecasting (Jänicke 1995) on the one hand, to microeconomic efforts of cost-reduction by increasing material- and energy-effciency, on the other hand. Some researchers propose to analyze material flows by types of social activities (e.g. transportation, or housing, see Baccini & Brunner 1991). My review of literature cannot represent this area of research adequately.

long-range historical perspective

So far there exist only tentative efforts at comparing industrial metabolism (structurally, or in terms per capita) with the metabolism of agricultural societies or with hunter and gathering societies. Usually this is done in a fairly sweeping way (Brunner et al 1994, Fischer-Kowalski & Haberl 1993). Some research from cultural anthropology (Kemp 1971, Rappaport 1971, Netting 1981, Kabo 1985, Cane 1987, Layton et al.1991) and agroecology (Loucks 1977, Gliessman 1978, Cooter 1978, Altieri 1989, Vasey 1992) should be of great help in establishing more systematic comparative perspectives. This would be important for any attempt at establishing standards of „sustainable development“.

Material flow analysis: Major conceptual and methodological options

I will now briefly summarize some of the strengths and weaknesses, some of the critical issues (resolved and unresolved), and some of the interesting results of the research tradition, but confine myself to overall material flow analyses on the level of national states or economies, and only briefly touch upon implications for meso- and microlevels.

This selection is influenced by the fact that it is this level where the institutionalization of data collection and publication by official statistics is most likely to be achieved, has been promoted by international guidelines (United Nations Handbook of Environmental Accounting 1993) and was successfully established in some countries (Japan, Germany, with others in preparatory stages). Most of the research in this field has been based upon available statistics (with the notable exeption of Baccini et al.1993), and would greatly gain from their systematic improvement. One of the tasks of contemporary research is its support for establishing appropriate concepts and operational definitions that will be of strong influence upon future research once they are institutionalized.

I will group my discussion of the literature around three issues. *First*: How are the boundaries between the socio-economic system and its natural environment defined, and what difference does this definition make empirically? *Second*: What is considered a materials flow (into, within and out of the system), and how are these flows classified? Again empirically: What are the respective proportions, and what are the social and political implications of these proportions? *Third*: What is the environmental relevance of materials flows? What are the criteria according to which this may be judged?

Socio-economic system boundaries and system compartments

With respect to the economy, the common denominator of „money" provides a practical guideline for distinguishing what belongs to the economic system and what does not. Tons or joules provide no such guideline - so the discussion about adequate system boundaries has marked the establishment of this research paradigm from its very beginning (Boulding 1966, Ayres and Kneese 1969). It seems though as if the formal attributes of the physicist's presumption of the constancy of mass and energy, as well as of (economic) input-output analysis, are being commonly used as a guideline, resulting in the following equation:

(1) The sum of material/energetic inputs into a system equals the sum of outputs, plus changes in stock.

This equation is usually applied to the system as a whole (Bringezu 1993a, 1993b, Steurer 1992, Bringezu et al.1994, Statistisches Bundesamt 1995, Evironment Agency Japan 1993, 1994, Baccini et al.1993, Rogich et al 1993a, Wernick & Ausubel 1995, Hüttler et al 1996), but not in an equally consistent manner to all its compartments or subsystems.

It would probably add to the clarity of distinctions to also consistently apply the following, second equation (Fischer-Kowalski 1997):

(2) The metabolism of the system equals the sum of metabolisms of its compartments or subsystems (however tricky the interplay between compartments may be).

This equation follows from a systems approach, looking at an economy or society as an integrated whole in the way biology does with an organism, and looking at its „metabolism" as a kind of highly interdependent self-organizing process rather than just an assembly of „material flows".[44] It also follows from the mathematics of input-output-analysis (Leontief 1970). Equation 2 would guide against several inconsistencies - often hidden - that so far can be observed in almost all studies.

[44] In no way do I wish to imply that one needs to import all the other connotations of „organismic" functioning.

The application of this equation requires explicit specifications of what the compartments of the system are. Concerning socio-economic systems on a national level, a broad consensus seems to be on its way. Most studies consider *human bodies* as a physical compartment of the socio-economic system.[45] But often this does not imply that the complete metabolism of human bodies be included. Typically human nutrition is included as an input, and excretion as an output, but both respiration, i.e. the intake of oxygen and the output of carbondioxide and water, and the deposition of dead bodies would be excluded from analysis (e.g. Ayres & Kneese 1969, Steurer 1992, Rogich et al.1993a, Statistisches Bundesamt 1995).

Similar considerations apply to to the inclusion or exclusion of *livestock as well as domestic animals*. It makes a big quantitative difference for socio-economic metabolism whether livestock is considered part of the socio-economic system (and consequently its metabolism part of the socio-economic metabolism), or not.[46] This again is a source of many inconsistencies, i.e. doublecounting (if both the crop harvested and then fed to livestock, and livestock products are considered as inputs, as discussed in Kneese & Ayres 1974), or omission (if crop fed to livestock is considered, while the amount of plant biomass consumed in grazing is excluded such as with Schütz & Bringezu 1993, Bringezu et al.1996, Stat.Bundesamt 1995, for a dicussion see Haberl 1997a). Also animal respiration is often not considered properly (it typically amounts to about 10% of societal oxygen consumption and, accordingly, of carbondioxide emission, Hüttler et al.1996), nor the effects of livestock upon the turnover of water (Hüttler & Payer 1997). If livestock is included as a physical compartment of the social system, meat and milk etc., of course, may not be treated as inputs from the environment, but have to be looked upon as transfers within the social system.

Theoretical considerations have been raised wether to include *plants* as compartments of the social system, insofar as they are maintained by labor in agriculture or forestry. If agricultural plants were considered as part of the socio-economic system, the boundary between this system and its environment would be „pushed outward", to the mineral level, except for fishing, hunting and gathering. This does not seem very practical, since it does not correspond to any existing economic statistics, and since it is very hard to

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[45] This may depend on the social system chosen for analysis, though. While it can hardly be avoided to consider humans as physical compartments of nation states, for example, it may be questionable to consider the bodies of the employees as compartments of a firm, and in fact it is rarely done. As has been suggested above, it makes sense to consider those objects as compartments of a system that the system is working to keep in a certain state. This may be the case for a firm's buildings and machines, maybe even the attitudes of its employees, but rarely their bodies (an exception maybe an opera, or a football club).

[46] Ecologically speaking, it makes a big difference on which trophic level human nutrition enters the material flow statistics. If humans live on a vegetarian diet, they need about 1/10 of the plant biomass (and the land required for this) compared to the biomass required if they feed on meat and dairy products. So if the statistics just count the materials weight of meat and diary products, and not the weight of the crops needed for feeding the livestock, they will come up with much smaller numbers.

distinguish between „social system plants“ and „natural plants“ (Fischer-Kowalski 1997). I do not know of any case where the distinction was actually drawn in this manner.

Finally, a consensus seems to exist to include *man-made and maintained technical structures* as physical compartments of social systems. This applies to buildings, machines, vehicles and the like, but also to roads, dams or sewers. If this is done, according to equation 2 all the materials that are used for making and maintaining these structures belong to the social system's metabolism, as well as the energy and the materials (such as water, air and various raw materials) used to make them function and produce those goods and services the social system has constructed them for.[47]

Once the physical compartments of the social system are defined, it is also possible to distinguish between „stocks“ and „flows“. Some efforts have been invested in this distinction (Baccini & Brunner 1991, Lehmann & Schmidt-Bleek 1993, Bringezu 1993 a,b, Wernick & Ausubel 1995, Fischer-Kowalski 1996), but so far no common practice has emerged. I would suggest to consider *equating „stocks“ and the material compartments of the socio-economic system* mentioned above. Such a definition provides a certain clarity and simplicity on the theoretical level, and a common guideline for operationalization. A reliable distinction between stocks and flows is a prerequisite for determining empirically whether a socio-economic system is still „growing“ (in physical terms), in a steady state, or shrinking. (Bringezu & Schütz 1995, Wernick & Ausubel 1995). This should refer to the size of the population, the size of the livestock and the weight of the infrastructure. Accordingly, an operational distinction between „size“ and „metabolic rate“, between the „growth rate“ and the energetic and material „turnover“ of the social system can be drawn. Typically, only the technical infrastructure (mainly: buildings) are considered as material stocks - and not the live beings, that is human and livestock populations. From a strict input-output perspective, this must result in inconsistencies, and theoretically this shows an „industrial“ bias hard to justify.

Lehmann & Schmidt-Bleek (1993), as well as Bringezu (1993a) and Bringezu et al. (1994), have suggested another mode of compartmentalizing the system turnover into goods, or production processes as elements, and of computing the material intensity of each production process of a good or service. Summarizing the relevant data provides a clue to the material intensity of the economy in much the same way as national accounting does with values added for gross national product. On a theoretical level, such an approach seems compatible with the one above[48], but raises some problems on the

[47] There remain some ambiguities that play a role in more technical debates concerning the operationalization of material flows. They concern both the borderline between the compartments of social systems and the environment (for example: the water in drainage pipes), and the distinction between stocks and flows. Practically, as we shall see below, it makes sense to consider built infrastructure as „stocks“ and all other physical goods as „flows“, even if they have a turnover time of several years.

[48] Indeed, it might be looked upon as the production side of the national product, as complementary to the expenditure side in economic input-output-analysis (Welfens 1993).

operational level that have not quite been resolved yet.[49] (Examples of this type of analysis: Kranendonk & Bringezu 1993, Stiller 1993.)

Whereas the boundaries towards the natural environment are still a matter of dispute (see also the next paragraph), a consensus has been reached with regard to handling the boundaries between different socio-economic systems. It is a common feature of all studies to distinguish between „extractions from the environment“ or „primary inputs“ on the one hand, „imports“ from other socio-economic systems on the other hand. The same applies to the output side: „depositions“ resp. „emissions“ and eventually „dissipative uses“ and „losses“ are distinguished from output in the form of „exports“ to other socio-economic systems. Imports and exports, as established so far, are being handled very much in the same fashion as by economic statistics (i.e. they do not include the import of imissions, for example). Specialized studies then may look into the material or ecological „rucksack“ of imported goods or services (Kranendonk & Bringezu 1993, Bringezu et al.1994).

2) Inclusiveness or exclusiveness of materials flows, and their classification

Even when the compartments of the socio-economic system are clearly defined, there remains a substantial fuzziness, on a theoretical level, with respect to the question: Where do material flows induced by economic activity or human labor start, and where do they end? This is the „cradle-to-grave“-problem that has been given much attention.[50] The choices made lie somewhere between a fairly restrictive definition following the boundaries of the economy (all materials that are economically valued are considered as inputs, but not, for example, earth removed for construction or used for ploughing. The same would be true, symmetrically, for outputs), or a very extensive definition including all materials touched upon by technology or labor. The differences implied with these definitions have the order of several factors of magnitude.[51] The more encompassing the definition becomes, the more the materials crucially needed in socio-economic metabolism tend to disappear quantitatively in the total; on the other hand, a neglect of the quantities of „translocated“ materials tends to hide environmental burdens associated with materials extraction from nature. A distinction that has been established, and has proved to be quite practical, is that between „used“ and „unused“ (but nevertheless mobilized) materials: Unused materials chronically are more difficult to quantify empirically but - by order of magnitude - are at least twice that of „used“ materials (Schütz & Bringezu

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[49] So, for example, it is hard to establish, let alone compare over time, what „one“ good or service is. For a case like orange juice, this seems relatively trivial; and the material flows associated with the life cycle of this good can be established. But what do you do if the service „hearing music“ were chosen? What difficulties one would encounter to compare the material intensity of this service between the U.S. and Germany, for example, or over the past 20 years?

[50] This problem has been imported from „life-cycle-analysis“ and ecobalancing of products, but of course also applies to socio-economic systems and the materials flows they instigate.

[51] An example from Wilmoth et al. (1991): In order to produce 1kg of gold, another 350 tons of overburden movement in extracting the gold are required.

1993, Statist.Bundesamt 1995). It may then depend on the purpose whether the larger or the more narrowly defined total is used.(see also Hüttler 1995 vs.Steurer 1992). Generally it can be said that the statistical basis of „unused" materials is usually much weaker, and does hardly lend itself to international comparisons or comparisons over time.

In another trial-and-error process it is being determined currently which relevant categories of materials should be distinguished. Whereas some of the pioneer work of Jänicke et al. (1992) sought to represent the total by some selected „strategic materials" (such as cement, water, steel, aluminum, chlorides, pulp and paper) that could be empirically established for many countries diachronically, others sought to break down (varying) totals into qualitative compartments. A useful strategy was chosen by Hüttler et.al 1996, 1997a, combining the common distinction - fuzzy upon closer scrutiny - of non-renewable vs. renewable resources, with the distinction between biogenic (energy providers: fossil fuels, biomass) and non-biogenic materials (metals, minerals on the one hand, air and water on the other), and analyzing each cycle of input-materials seperately. Most other studies use varying less systematic distinctions relying upon existing statistical traditions. (e.g. Rogich et al.1993a,b, Statistisches Bundesamt 1995)

It seems to be feasible - given the economic statistics available - to establish the overall material *input* (with imports on a national level amounting to no more than 15-20%, Schütz & Bringezu 1993, Environment Agency Japan 1993, 1994, Steurer 1992, Wernick & Ausubel 1995, Statistisches Bundesamt 1995, Hüttler et al.1996). While this leads to internationally comparable results once the same definitions are applied (Jänicke 1995, Hüttler et al.1997a), it appears to be very hard to approach the same goal from the „*output*"-side, from an estimate of wastes, emissions and dissipative losses (Baccini & Brunner 1991, Baccini et al.1993[52]). It is one of the main insights of this type of research, maybe, that - however sophisticated the world of products and services in industrial economies may appear - there is a very limited number of quantitatively important input materials. Interesting enough, the main „free environmental goods", i.e. water and air, make up by far the largest proportion (somewhere between 85 and 90% of the total), and much of the rest is spent on fairly basic functions such as construction of housing and infrastructure, food & fodder, and the provision of technical energy (Fischer-Kowalski & Haberl 1993, 1997a).

The residues of the metabolic process, however, i.e. the outputs to the natural environment, tend to be both chemically and physically complex and hard to establish in a systematic quantitative manner. Three decades of emissions- and waste statistics have generated a considerable amount of classifications, usually differing for each medium

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[52] That per capita-values of material throughput calculated on the basis of these data are very much at variance with all other data also results from the fact that Baccini et al. use a different unit of analysis: Their basic unit is the household and, therefore, they miss all the materials which enter the production process but get lost as wastes before they ever become goods for final consumption.

into which residuals are discharged, that can hardly be summarized (or internationally compared) to generate an overall picture. What may come as a surprise for many, however, is the fact that in most countries it seems to be the atmosphere that serves as the waste-deposit which is most important quantitatively. So far, there is little agreement in studies on socio-economic metabolism when it comes to the classification and statistical handling of outputs, as well as residuals, to the degree of theoretical inconsistency (e.g., in the treatment of animal manure as a recycling process within agriculture or as a „dissipative use“ of material). These problems can hardly be resolved without explicit input-output-models.

3) What appears to be the problem with socio-economic metabolism?

Why bother with industrial metabolism? What should be worried about? What are the major concerns as well as major remedies? The answers to this question originate from a wide spectrum of world-views and scientific paradigms. Without any pretention of theoretical stringency, I will try to loosely group them into the following six issues.

1. Exhaustion of resources. With respect to so-called „renewable resources,“ this concern dates back to the very beginnings of political economy and the theory of diminishing returns (originally with respect to agriculture). Now there are specialized discourses centered around the old issue of population-food-agricultural productivity-erosion (and, more recently, de-forestation) as resource-oriented approaches (e.g.Brown H.1956, Woodwell 1970, Brown L.1970, Kates 1994, Munasinghe & Shearer 1995), and a more conservationist approach concerned with the limits of human appropriation of plant energy (NPP) and its effects on biodiversity (Vitousek 1986, Wright 1990, Haberl 1997b). A second major concern are freshwater resources (Wolman 1965, Gleissman 1993). These concerns are very important in the contemporary debate on sustainable development, but somewhat less for the discussion of socio-economic metabolism. In this tradition the possible exhaustion of so called non-renewable resources has always been prevailing, whether this concerns fossil energy resources (Scarlott 1956, Meadows et al.1972) or metals and mineral ores (McLaughlin 1956, Ordway 1956, Brown H.1970). The „limits to growth“ that repeatedly have been projected did not assert themselves yet.

2. Pollution. Pollution was clearly the dominant environmental concern in the last decades and, of course, also played a role in the paradigm of socio-economic metabolism. (e.g. Ayres & Ayres 1994, Ayres et al 1994, Weidner 1995) Basically, however, the paradigm of system metabolism sought to overcome the pre-occupation with single, usually toxic pollutants often procured in very small amounts, and drew attention to the ecological effects of large material flows. The paradigm permitted the anticipation of possible global climatic effects of (non-toxic) carbon-dioxide emissions for their sheer amounts at a time when hardly anybody was considering the possibility of such an effect (Ayres & Kneese 1969).

3. Entropy. The concept of entropy and of human economic activity contributing to entropy, generalized by Georgescu-Roegen (1971) from energy to matter, has entered the debate of material flows time and again. „Dissipative losses“ or the „dissipative use of materials“ serve as qualifications, but it seems that the abstractness of this concept is too demanding for more common empirically oriented minds. Time and again, attempts are being made to interpret the whole process of societal metabolism in terms of entropy (Georgescu-Roegen 1980, Odum H. 1988, Binswanger 1992, Ayres 1994a).

4. Inefficiency of services. The basic idea that it is neither energy nor materials that are needed for the satisfaction of certain needs, but services, and that these services should be rendered with the least amount of material and energy investment, belongs to the core ideas of this research tradition (Ayres & Kneese 1969). Optimizing the material relationship between material and energetic inputs on the one hand, and the services produced on the other hand, serves as a strategic goal, and results in several comparative measures of energetic or materials intensity (Schmidt-Bleek 1993, 1994, Fischer-Kowalski et al.1994). This corresponds well to basic technological rationalization strategies (e.g. Weterings & Opschoor 1992, Schnitzer 1992).

5. Closing open cycles. The idea of creating closed cycles („closed-cycle-economy“) that neither force to extract ever new resources from the environment nor spill over large amounts of residues has always been very attractive to technicians who had made the experience that pollution could be minimized if cycles were closed by adequate technical means (Kisser & Kirschten 1995). The recycling of waste materials was one of the policy issues that promised relief both ideologically and practically. Upon closer scrutiny it is obvious, however, that this option applies only to a narrow range of processes (Overall recycling rates of materials on national levels nowhere exceed 5% of input, and this cannot be simply attributed to polical inertia, cf. Jänicke 1995).

6. Size and growth of metabolic throughput. Various authors argue that, irrespective of the further effects socio-economic metabolism may have upon the environment, it is the sheer size of turnover that presents a burden. Moreover, if an industrial metabolism of this dimension serves as a development model for the rest or the world, resources and sinks for residuals will be hopelessly overburdened within a short period of time. (Weizsäcker et al. 1995, Schmidt-Bleek 1994). Meadows et al. (1972, 1992) add to this argument the problem of speed: The more rapid the movement (of growth), the more time elapses between the moment when people become aware of some danger and an effective reaction. For the same reason, Daly & Cobb (1989) used the popular image of a lake with water-lilies which double their numbers every morning: The time-span between the moment when the lake is half filled and when it is full is but one day.

With respect to considerations of „sustainable development“, to which most of the contemporary analyses of socio-economic metablism relate, all arguments reviewed above are in the process of being re-positioned in a framework of inter-generational, and often also international, equity.

Conclusions

As has been noted before, sociology is not well equipped to deal with the interactions between society and its natural environment. Is it possible that a concept like socio-economic metabolism may provide sociology with a tool it can handle, that would relate to its scientific traditions, and that would permit the use of its methods, thus stimulating research? What would be the tasks that sociologists, in particular, might tackle?

As far as the interdisciplinary discourse on indicators of environmental performance of society is concerned, it appears that socio-economic metabolism and the analysis of material flows provides powerful tools to integrate various concerns. The overall material and energetic turnover of national economies constitutes macro-parameters for environmental performance and efficiency that compare well to the established economic macro-parameters generated by national accounts. Even the methodology and the data-base behind these parameters are similar, which makes these concepts easily transferable within the arena of economics and of economic and industrial politics.[53] It also smoothly fits into the way technicians or managers think of efficient processes, and it operates with notions which the life-sciences are well acquainted with. This general capacity of these concepts for easy communication seems to garantee their success within the interdisciplinary arena of environmental politics. Let me briefly review the merits already achieved and the promises still pending according to the following criteria: Theoretical stringency, research productivity and political relevance.

theoretical stringency

As was apparent in the above review of literature, the core concepts are fairly simple and work on several different levels of abstraction. This makes them highly communicable between different academic disciplines, and beyond this, in public discourse. This may be looked upon as the most important strength. So far, a consensus seems to have emerged concerning the overall procedures, but most theoretical and operational specifications are not properly and consistently settled yet. This process will be supported by large scale international panels of researchers aiming at harmonizing concepts and methods[54], and by corresponding steps on behalf of national statistical offices towards an integration of material flows into standard statistics in an internationally comparable manner.This integration of data collection and publication in national statistics will be crucial for the future of this approach: On one hand, as it has happened with economic national accounting, the official statistical categories will exert a strong influence upon future concepts and definitions in research. On the other hand, statistical offices will probably handle them with a care for consistency and continuity which the scientific community

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[53] Jänicke, 1995, uses the German term „Politikfähigkeit", i.e. topics which are commensurate for politics.

[54] Such as the program „ConAccount" under the leadership of the Wuppertal Institute financed by the European Union for 1996/97

itself would not be well equipped to secure.[55] I would conclude, therefore, that socio-economic metabolism and material flows between society and nature are on the verge of becoming well defined and agreed-upon operational tools, providing macro-indicators for the environmental performance of societies that can be compared internationally, intertemporally and with respect to subsystems of society, and that may be related to many other social and economic variables.

research productivity

As can be gathered from the above review, the most recent years have seen a virtual explosion of research relating to socio-economic metabolism - the approach has aquired a major share among alternative social-science approaches towards environmental problems. If one looks at content, however, one still finds mostly research efforts to establish empirical quantities of material flows, therewith striving to clarify operational definitions. As yet, there is very little research linking the characteristics of metabolism to other social or economic variables. There are some efforts to relate material to economic growth (such as Auby 1985, Opschoor 1985, Binswanger 1993, Jänicke et al. 1993, Rogich et al.1993, Hüttler et al.1997b, Kuhn et al.1994, Picton 1996), demonstrating a relative independence; there is a lot of technical and microeconomic research on material and, in particular, on energy-saving potentials (which I have not referred to in detail in this review) and needs in favour of a more sustainable form of devolopment (e.g. Weterings & Opschoor 1992, Enquetekommission des Deutschen Bundestags 1995). But there is as yet not much research of a more sociological nature or with a bend towards political science. This may be expected to increase as soon as basic definitions and data generation procedures will have become, as may be expected, more standardized.

political relevance

All social-science research dealing with „environmental problems“ aims at political relevance, intends social change, sometimes at the price of clarity and depth of analysis. Research on socio-economic metabolism is no exception to this rule. Most of this research unites behind the effort to establish paths of „sustainable development“ for industrial society. It legitimates its focus on highly developed industrial countries by stressing their dominant position in shaping the world economy and their role as models for economic development. Several of the parameters from materials flow analysis serve as devices to define targets for national programs of sustainable development.[56] Some even use the overall material turnover as a targetting variable for reduction („factor 10“,

[55] It may happen though, as has been observed in several countries lately, that severe cuts in public spending diminish the means of statistical offices to proceed along the internationally agreed path (UNO 1993), and may even lead to a termination of neccessary basic statistics that research has been using so far for the purposes of material flow analysis.

[56] Such approaches are in line with some of the more detailed international agreements, such as the reduction goals for carbondioxide agreed upon in Rio de Janeiro.

Schmidt-Bleek 1994, or „factor 8“ as with Weizsäcker et al.1995). Whereas quantities of material flows lend themselves very well for the operational definition of political goals, it takes an extra effort to relate them to goal-oriented strategies - an effort that, in most cases, has yet to be made (several examples see in Jänicke & Weidner 1995).

It can be taken almost for sure, therefore, that socio-economic metabolism is going to become one of the most powerful tools in describing and analyzing environmental problems as well as problems of sustainable development on a macro-level. Whether it is going to become a powerful tool in the way sociology is looking upon society remains to be seen. As was apparent from the approaches reviewed in the first part of this essay, cultural anthropology did tradionally make use of concepts related to metabolism and, therefore, could join the first stage of research efforts arising in the course of environmental concerns. Sociology, on the other hand, had little to build upon, and a lot of epistemological resistance against taking nature serious. With regard to socio-economic metabolism, it is also sociological skills that are required. They are required to generate a sufficiently complex image of the social system and the way it works - otherwise it will be neither possible to understand, let alone to change, the intricate ways in which socio-economic metabolism is regulated.

It could be an ironic contribution from environmental sociology to the discipline at large to spread the message that consumerism should be accepted, after all. For such a long time social theory has been focussing on labor and the technologies by which labor might achieve something. Now, finally, the focus on metabolism suggests to start looking at the services this process renders and the desires it fulfils: We must begin to take a closer look at alternative ends rather than alternative means to attain given ends.

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