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Material Flow-based Indicators in Environmental Reporting

Joachim H. Spangenberg
Aldo Femia
Friedrich Hinterberger
Helmut Schütz
with contributions from
Stefan Bringezu
Christa Liedtke
Stephan Moll and
Friedrich Schmidt-Bleek

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European Environment Agency

NOTE

A great deal of additional information on the European Union is available on the Internet. It can be accessed through the Europa server (http://europa.eu.int).

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European Environment Agency
Kongens Nytorv 6
DK-1050 Copenhagen K
Tel. (+45) 33 36 71 00
Fax (+45) 33 36 71 99
E-mail: eea@eea.eu.int
Home page: http://www.eea.eu.int

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Foreword

The European Environment Agency is actively involved in developing indicators to evaluate progress in the state of the environment and in the policies designed to improve it. Clearly, indicators are linked, or should be linked, to current and emerging policy frameworks, and the implicit and explicit targets contained in them. This raises the question: what are those frameworks?

Experts' Corner Reports constitute a forum for disseminating views on new developments in environmental policies and for translating these into practical consequences for the European Environment Agency and others involved in producing information for framing and implementing environmental policies.

The previous report in this series, 'The Concept of Environmental Space' by John Hille, discussed possible choices for indicators, against the background of the limits to the rate at which we can exploit the Earth's resources. In conclusion, the report points to the need for focusing more on indicators concerning inputs into the economic system.

This new report follows the same line of reasoning and explores in detail material flows in the economy which have a possible influence on the environment. Amongst others, it explains the aggregated indicator 'material intensity per service unit' (*mips*) – and suggests some applications.

The *mips* indicator is an interesting example of an eco-efficiency indicator, linking a 'driving force' with a 'pressure' on the environment. In view of the current growing attention for eco-efficiency indicators, I recommend this new report to all readers interested in indicators, material flows, eco-efficiency and sustainable development.

Domingo Jiménez-Beltrán
Executive Director, EEA

Copenhagen,
October 1998

1. Introduction

All our economies are dependent on the life-sustaining systems of the ecosphere. This long ignored fact came high on the political agenda only when the economic implications of environmental damage became obvious or at least foreseeable. To name just a few:

- Degradation of marine resources causing the decline of fisheries (a steady decline since the 1992 record high);
- Deforestation (17 mn ha/yr) and loss of soil fertility (net loss of fertile soil: 26 bn t/yr) threaten future agricultural productivity and cause increased demand and cost for fertilisers;
- Depletion of water tables and ground water pollution not only put human water supply at risk, but diminish the use of whole areas for agricultural purposes;
- Lake acidification (in about 80% of Scandinavia) and forest depletion (about 40% in Europe) have been fought at high cost. Nonetheless, the losses of forest value are obvious and have not been compensated;
- Stratospheric ozone depletion (varying from 5% up to 95% depending on season and geographic location), is increasing and not only endangers human health but decreases agricultural and marine yields as well;
- Greenhouse gas accumulation in the atmosphere (+28% since industrialisation began) causing a change in the average temperature will increase the number of weather irregularities, storms and altered rainfall patterns at an enormous cost for economy and society;
- Clear-felling of forests instead of sustainable management has been speeding up the loss of biodiversity (about 17,000 species/yr), a crucial resource for the pharmaceutical and agricultural industry.

> "Eventually, given the non-linear behaviour of complex systems, and the possibility of multiple post-perturbation states, the possibility exists that the ecosphere may "flip" into a configuration unfavourable for continued civilised existence (W.I. Rees)".

The physical dimension of the global crisis is that, on current practice, our environment is over-used and the stability of our life-supporting systems is threatened.

The second dimension of the global crisis is a distributional and social one: labour has been undervalued (underpaid in the US and underused in the EU, sometimes both as in some Central and Eastern European countries).

The third problem of our economies is that instead of them offering innovative solutions to new problems (e.g. ageing societies, global competition, dematerialisation of services) and thus creating new markets, new business opportunities and additional employment, business is predominantly obsessed with cutting costs for the supply of yesterday's solutions for tomorrow's problems.

Consequently, we are producing too little wealth from too much resource, and we distribute the wealth produced too unevenly.

Although this paper will focus its considerations on the environmental dimension of sustainability, it always has to be remembered that without taking fully into account the social and distributional dimensions, sustainability as such cannot be reached.

In the context of this triple crisis, and with the corresponding approach of combining social, economic and environmental goals, the notion of sustainability as proposed by the UN Commission on Environment and Development has proven widely attractive. It refers to a socio-environmental concept, attempting to harmonise two principles previously regarded as being contradictory: environment and development. It foreshadows a means of economic development that secures a quality of life for all people, without over-burdening ecological systems. The failure of politics to provide long-term perspectives, taking into account peoples' needs, wants and priorities is at the basis of the growing dissatisfaction with the political system as a whole. This dissatisfaction, if not treated properly, could easily undermine the political basis of European integration, in particular with the heavy tasks that lie ahead of enlarging the community. Talking about sustainability for Europe thus also means talking about the very future of the European Union.

2. The Concepts of Sustainability, Carrying Capacity and Critical Loads

Both the anthroposphere and the ecosphere are non-linear complex systems – the former viable only in dependence on the latter. It is, therefore, not trivial to ask what practical and directionally safe criteria may apply in order to guide economies within ecological guard-rails, i.e. enabling the Earth's systems to remain in a balance. Nor is it trivial to attempt to harmonise any conceivable approach at the international level, since there will always be both winners and losers. Eleven years after the publication of "Our Common Future"([1]) the international dialogue on these matters is, in fact, intensifying.

In this paper, we offer some thoughts which may also serve as a conceptual framework. We attempt to define the relevant parameters that need to be taken into account to steer human development towards ecological sustainability. We further propose a measure for resource productivity in the economy and demonstrate its usefulness by means of three case studies in different sectors of the European economy. Furthermore, we show how quantitative targets for sustainable resource consumption can be derived and used to define performance indicators which either can be used as policy steering instruments in their own right, or can be rendered operational within the frameworks of the EEA or the UN-CSD work on indicators.

We suggest that the following four issues be addressed when attempting to make operational the concept of sustainability:

- a practical framework for the integration of the economic, social and environmental dimensions of sustainability;
- a clear definition of the categories to be taken into account for each of the dimensions;
- methodologies to monitor progress towards sustainability for each of the categories; and
- targets in order to measure distance-to-target (performance indicators).

The *physical* dimension of sustainability refers to leaving intact – for an infinite length of time – the stability of the internal evolutionary processes of the ecosphere, a dynamic and self-organising structure. The ecosphere, as well as the anthroposphere, is part of a larger system, and open to flows of either materials or energy, or both. Thus, the anthroposphere is an open, thermodynamic subsystem of the earth with respect to materials and energy. And the earth is – for all practical purposes – closed to flows of external matter but open to energy inputs, consisting mainly of solar radiation. It is primarily this window to energy inputs from space which provides room for a sustainable use of natural resources for mankind.

An economic system is environmentally sustainable only as long as it is physically in a (dynamic) steady-state, ie. the amount of resources used to generate welfare is permanently restricted to a size and a quality that does not overexploit the sources, or overburden the sinks, provided by the ecosphere. Without this:

- human economies would have to continue to draw on the *stock* of natural resources (e.g. high grade ore, crude oil, fertile soil) or, from an energy viewpoint, they would continue to use up low-entropy resources like minerals or fossil fuels which sooner (3rd millennium) or later (4th) will be depleted ([2]);
- the immense (and rapidly increasing)-*flows* of resources through the global economies would continue to lead to an increase in entropy, resulting in a variety of unpredictable and irreversible environmental impacts. These include slow, long-term changes such as global warming, as well as short-term irregularities such as storms, stronger hurricanes and flooding rivers, resulting from the destabilisation of ecological systems. This is equivalent to threatening the life-support system of mankind.

The maximum acceptable environmental concentration (a stock) of anthropogenic outputs, usually well above the no-effect level, has been called the *critical load;* it is the basis for calculating the maximum continually supportable rate of output, dependent on several chemical characteristics and, in particular, on accumulation and biodegradation characteristics of the substance analysed.

The maximum continually supportable rate of resource extraction from a given ecosys-

tem (a flow) has been termed that system's *carrying capacity*. This term originates from biology, where the carrying capacity is defined as the number of individuals of a given species that can be sustained over time without overburdening the host system. Such a measure must, obviously, consider the average long-term per-capita resource consumption of all natural species. As for the human race, one must remember that not only is the world population still increasing sharply, but the *per capita* consumption of natural resources (energy, materials, space) is also on the rise, resulting in an even steeper increase of overall resource consumption. This is – or must lead to – an unsustainable situation.

As current experience indicates, we are already at, or even beyond, the limits of carrying capacity. Due to the technical skills of mankind , its innovative drive and the material growth of the anthroposphere, an infinite number of – ever-changing – disruptive interactions can occur at the boundaries to the ecosphere. Moreover, these impacts are characterised by non-linear relationships between stresses and responses. An unknown quantity of these effects can neither be detected within human time horizons, nor – were they found and measured – could they be attributed to distinct causes ([3]). This precludes the observation or theoretical calculation – and thus quantification – of the totality of concrete consequences of human (economic) activities on ecosystems ([4]). This also illustrates the limited power of cost-benefit analyses in shaping environmental policies, particularly regarding the systematic restructuring of the economy in the push toward sustainability.

Since neither the carrying capacity nor the critical load can ever be precisely determined, the political application of these science-based concepts must necessarily take into account the precautionary principle. This means that decision-makers must steer the economy not by scratching the guard-rails, but by staying clear of them, keeping the economy in the middle of the road towards sustainability.

3. Environmental Space

Leaving the field of basic science and coming one step closer to its application in the socio-economic field, we now introduce the notion of *environmental space*.

Environmental space ([5]) is a normative concept which takes into account the physical as well as the social and developmental aspects of sustainability. Physically, environmental space is described as the capacity of the biosphere's environmental functions to support human economic activities, the upper limit given by the carrying capacity. The social dimension of environmental space is given by the "global fair shares" or "equity principle" derived from the definition of sustainable development, assigning to all living people a right to achieve a comparable level of resource use, and to future generations a right to an equivalent supply. This is equivalent to the principle of inter- and intra-generational justice of distribution. Obviously, such a right cannot be implemented in a straightforward manner – it is a human right to use a fair share of the common heritage of mankind rather than a piece of enforceable legislation.

„[We have] to create, and above all apply, different, new or complementary ways to measure the progress towards metabolically healthier, more sustainable socio-economic systems where the main pillars are increased efficiency (in the use of all kinds of resources, not only natural), equity (now and for future generations) and improved quality of life."
Domingo Jiménez-Beltrán, Executive Director, European Environment Agency

Given the uneven distribution of resource use today, a significant reduction (e.g. by half) in the use of environmental space is needed. It translates into a need to reduce the physical resource consumption of industrialised countries drastically, in this case by a factor of five to ten, i.e. by 80% to 90%.

This calculation is based on two explicit assumptions: that we are already at, or beyond, the limits of carrying capacity, and that the equity principle of intra- and inter-generational justice should be applied. The calculation can be used for policy guidance only if its two basic assumptions are shared by the decision-makers and supported by the individuals concerned.

Environmental space between overconsumption and need Figure 3.1.

Source: J. Spangenberg, U. Tischner, Wuppertal Institute, 1994

Figure 3.1. illustrates the environmental space between overconsumption and need and shows the upper "ceiling" limit. (Besides) this "ceiling" to resource use, there is a "floor" of resource availability necessary in order to lead a quality life, this needs no further elaboration here, since it has limited meaning for EU societies ([6]). Within these boundaries, a sustainable economy should flourish, providing goods and services to meet human needs, generating enough financial surplus to pay for investments and providing enough jobs and income to avoid social tensions.

"Environmental space" as defined so far, however, is not operationable. In order to make it a viable, science-based policy tool, the categories to be analysed need to be defined (e.g. State of biodiversity ? Output of CFCs ? Input of materials ?).

3.1. Principles of Measuring Environmental Space

There are several options to describe the use of environmental space, all of which may be helpful for specific purposes. From our point of view, the chosen option needs to identify those characteristics that permit easy translation into policy action, in a directionally safe manner.

3.1.1. State versus Pressure

Using descriptions of the *state of the environment* and the impact that specific pressures have caused (e.g. forest depletion or number of endangered species) can help illustrate the need for immediate action and guide curative measures. Due to the complex character of environmental systems, however, and in particular to the widely unknown unintended side-effects, it is hardly ever possible to clearly identify underlying causes, and thus not possible to design appropriate policy responses to the driving forces of environmental degradation.

We propose, therefore, not to focus on the state of the environment, but rather on the underlying pressures with an inherent damage potential in order to single out cause-oriented improvement measures. ([6])

3.1.2. Stocks versus Flows

Taking the state of the *stocks of environmental resources* (existing biodiversity, reserves of fossil fuels and minerals etc.) as a measure may indeed be the basics of resource economy, but this provides hardly any information about the environmental situation and trends. As an example coal in the ground does not cause environmental harm, unless it is mined and burnt. Resource stock assessment is, therefore, an inappropriate measure for the use of environmental space.

Unlike stocks, however, *resource flows* are of key importance for environmental deterioration, providing good estimates about the use of environmental space. The throughput of resources (called the "scale" by H. Daly), however, must be measured at a well-defined point to permit the reproduction of data and international harmonisation. The most appropriate choice for this point of measurement is obviously the border between the ecosphere and anthroposphere (or humansphere, as W. Rees calls it). Since there are functionally two of these borders, on the input as well as on the output side, we now have to compare the usefulness of choosing one of these options.

3.1.3. Output versus Input

Traditional environmental politics has focused on regulating the output side of the economy. Pollution abatement equipment, BAT (best available technology) for emissions reduction, critical loads assessment, all these measures are different ways of reaching the same goal: influencing the quality and quantity of the outputs our economy releases into the ecosphere. Environmental research, as well, has focused on the interaction of anthropospheric outputs with the ecosphere, with great effort invested, and limited – albeit important and helpful – results.

On the other hand, input-related regulations have long been known as well, such as fleet efficiency regulations or licences for mining (relative-input limitations) and for logging or ground water extraction (absolute-input limitations). For operationalising the environmental space concept, then, which approach is more suitable? Some figures from the German economy, typical of industrialised economies, illustrate why we prefer input-based models:

- Whereas the number of materials entering our economic systems is limited to 50 - 100 distinct abiotic materials including energy carriers, output control has to handle about 100,000 substances from the chemical industry alone, each of which interacts in various ways with the ecosphere and the other substances emitted.

- Whereas the number of points of entry into the anthroposphere is limited to some 20,000 ([8]), the exits are beyond enumeration: every smokestack, every exhaust pipe, every waste dump, every drainpipe is such an exit.

When designing appropriate policy measures, focusing on the inputs can provide higher regulatory efficiency with much less effort in control. This becomes particularly important when the introduction of market-based financial instruments is considered: regulating outputs with financial instruments will either need a new control bureaucracy or generate the risk of massive free-rider effects (on instruments, see also Chapter 7.5).

3.2. Categories of Environmental Space: the Importance of Material Flows

Every use of environmental space needs a realm where it can take place, and materials as the physical basis of the agents and their instruments (including energy carriers). These are three at least partially independent variables: the relationship between the amount of tonnes of materials, kilo-Joules of energy and hectares of land used to produce one item varies from product to product and from service to service. Thus, we propose these three – materials, energy and land – to be the core categories of environmental space. Each can also – if necessary – be split up into environmentally relevant subcategories such as air, water, soil, biotics and minerals for materials; fossil, renewable and nuclear sources for energy, or built-up, pasture and agricultural uses for land.

We propose characterising the physical aspect of the use of environmental space through a quantification of the input flow of energy, materials and land of a given economy. Consequently, we propose defining the categories of environmental space to be the critical parameters in order to approach sustainability.

The proposed methodology, based on the (at least partial) independence of the three dimensions analysed implies the need to keep the three indicators separate. There is no scientifically sound way to integrate them, i.e. to express land use through material flows or material flows through energy. Energy, land use and material flows have no common unit by which to measure their use. Any integration ([9]) remains either simplistic or arbitrary (e.g. by defining standard conversion factors). Although this is an obstacle (from our point of view, a minor one) to communicability, this has to be accepted for the sake of adequacy, transparency and – consequently – credibility.

This report, however, focuses on the material flows induced by human activities. Every movement of materials and every transfer of materials from one place to another has repercussions on ecological linkages and alters the environmental balance. Ecological changes brought about in this way are technically irreversible. Therefore, given a certain supply of services, sustainable development means a reduction of material flows needed to create these services.

Any meaningful estimate of the environmental sustainability of consumer goods and services must be carried out "from the cradle to the grave" (or to the cradle, for recycled goods) if misperceptions (due to only partial consideration of the life-cycle wide impact) are to be avoided in the future. Hence, assessments of ecological effectiveness must evaluate all material flows set into motion by people: each use of a natural resource, be it water for drinking or cooling, minerals for industrial production or construction, land for agriculture or air for breathing inevitably increases the entropy of the overall system. We consider the total material flow an appropriate measure of the potential disturbance, and we regard the reduction of material flows a necessary (although not in all cases sufficient) means of reducing the pressure of human species on the global environment in a directionally safe manner. The goal of reducing material flows is proactive, in that it does not refer to individual symptoms of environmental damage, but to the overall impact on the system, thereby trying to prevent future damages as well as reducing the current potential for disturbance. Although a *direct* link of material flows to environmental stresses is evident only in a minority of cases (as was the case with total energy consumption until the threat of global warming from CO_2 emissions was taken seriously), many of the well-known symptoms of environmental degradation, from declining fish stocks to reduced fertility due to e.g. heavy metal accumulation, can doubtlessly be linked to intense material flows as the indirect cause. Consequently, we consider *dematerialisation*, the dramatic reduction of anthropogenic material flows, of utmost importance for an ecologically positive change in our economic structures. **In other words, *dematerialisation can help to***

make operational the concept of sustainable development.

3.3. Setting the Targets

Although today, due to a level of technical efficiency well below the theoretical maximum, more than the necessary amount of entropy and waste is produced, but there is a theoretical minimum of entropy generation associated with every activity, and thus with every kind of material flow. However efficient production will be, even at the theoretically possible maximum, there is still unavoidably a significant amount of waste and entropy generated with every unit of materials and energy used. So the key question which needs to be answered is: which level of waste and entropy generation will have what destabilising impact on life-sustaining ecosystems, i.e. "Where are the limits ?".

Although the need for targets is broadly acknowledged([10]), they are conspicuously lacking in most of the existing environmental reporting systems (with few exceptions like EEA's 'Environment in the European Union 1995'). This obvious contradiction is not too surprising, given the lack of universally accepted environmental goals. The existing targets, however, focus on categories different from those proposed here, in particular they are lacking targets on material flows.

For energy, reductions have been recommended by the IPCC, supporting the idea that a reduction of about 50% is necessary. These are already the scientific basis for the ongoing political negotiations on a CO_2 reduction protocol. We therefore need not go into any further detail of energy consumption measurement and reduction here. For land use, the need for a sustainable pattern is evident from the threats to biodiversity and soil fertility loss, in Europe particularly, due to erosion and the leaching of micronutrients. However, so far no broadly accepted measure for biodiversity exists, and probably none can be developed to quantitatively cover the ecosystem, species and genetic level of biodiversity, not least because of the lack of data. Consequently, the criteria for a more sustainable development are more qualitative than quantitative in nature as described in earlier publications. ([12])

Our main concern here is to focus on material flows: in addition to non-renewable minerals, ores and biomass, these include all energy carriers, thus offering a broad basis to assess the environmental impacts of resource use, covering energy consumption and (at least partially) the impacts of land management systems. Calculations by Hans Opschoor, based on a different methodology rooted in resource economics, result in reduction targets between 50% and 90% ([13]); the "ecological footprint" calculations of Wackenagel/Rees ([14]) propose reductions of a similar size, as do a number of other authors ([15]). The need for a significant, albeit not yet precisely quantifiable reduction in resource use seems to be proven, and in order to operationalise it we have to set a figure, which – due to the current state of scientific knowledge – will definitely not be precise, but will be "correct" in the sense of being directionally safe, i.e. indicating the right direction in which to move: a compass, not a road map. A reduction of worldwide anthropogenic material flows – which are already greater than those arising from natural processes ([16]) – to one-half of the present dimensions, is a reasonable indicative goal (there is no scientifically proven reduction target yet). If it turns out that in the long-run, a 40% or 60% reduction in material flows is needed to reach sustainability, this makes no significant difference in terms of policy since the necessary reversal in the current trend of globally increasing material flows is the same, as any sensitivity analysis will show. ([17]) On a global per capita basis this would result in an average reduction target of 85% - 90% for Europe ([18]). This is in line with the above-mentioned sources.

Decreasing resource throughput in absolute terms does not mean compromising wealth (service availability and well-being) since technological and social innovations, changing demands and definitions of well-being as well as increasing resource productivity can compensate or even over-compensate for the difference in materials' use. Ecological product circles, recycling cascades, product longevity and eco-efficient services are means to reach this goal without sacrificing the quality of life ([19]). This is also the basis for the current incorporation of significant reduction targets into policy considerations in different countries ([20]). Therefore, developing a measure to quantify material flows is of utmost importance for any attempt to operationalise the concept of sustainability. Operationalisation means that the definition is clarified and an empirical content is assigned to the concept, so that a (real) policy can be built upon it.

3.4. Resource Productivity Times Ten

By how much does resource efficiency have to be increased? As mentioned, a factor two absolute reduction of material flows on the global level combined with the equity considerations, translates into a factor 10 reduction in resource use in the industrialised countries. If overall economic production is not to be reduced, this goal, to be reached in a 50 year time-span (needed to allow the technical, social and economic dynamics to adapt and adjust without major conflicts), is equivalent to an annual increase in resource productivity of 4.5% and can be considered a pragmatic, feasible and necessary policy target. This is all the more necessary if, alongside technology improvements such as those forecast in the US technology development or the Dutch sustainable technology DTO programme ([21]) and the resulting *efficiency* gains (more services from less resources), a culture of *sufficiency* (greater quality of life from less services) must emerge among the populations of industrial countries, accustomed to levels and – more important and problematic – to *forms and dynamics* of well-being which cannot be sustained in the long run.

A delinking of economic development and material use has been reported in the past ([22]), however this endogenous trend towards lower material use is not sufficient from an ecological point of view:

- because it is not the "intensity of use", but the absolute quantities used, that matter for environmental problems;
- because these empirical findings are either referring to *refined industrial materials* and not primary ones (a defective measurement methodology) ([23]) or – in an even more limited sense – to the delinkage of certain emissions (SO_2, NO_x), which are not indicative of a reduction in the total throughput of the respective economy;
- because the trend is too unstable (after delinkage, relinkage occurs) ([24]), too weak for the necessary changes to come about before it is too late, and is often driven not by the economic dynamic itself, but by legislative measures, i.e. dependent on political interference in the economy.

For these reasons, it seems obvious that dematerialisation is, unfortunately, not a likely result of mere "endogenous" economic evolution. Instead, active political pursuit is necessary.

4. A Methodology for Measuring Material Flows

To operationalise the concept developed so far, quantitative targets for the permitted use of environmental space must be made measurable with a standardised methodology, delivering meaningful, transparent and reproducible information about the total material activated by the production, use and disposal or recycling of a certain product or service. The resource-efficiency measurement concept *mips* (material input per unit of service) was introduced for this purpose, i.e. in order to transform the use of the environmental space in a measurable way and to translate its limits into directionally safe and quantitatively measurable targets ([25]).

Mips is an interlinkage indicator based on the Material Intensity Analysis (MAIA or MIA) developed at Wuppertal Institute. It measures material inputs (*MI*) at all levels (product, company, national economy, region ([26]) including all "ecological rucksacks", i.e. the total mass of material flows activated by a consumption item in the course of its life cycle (for details see Chapter 4.1.1). In the *mips* concept this *MI* is referred to the end user service (*ps = "per service"*) derived from that flow as a standardised reference (on the service concept see Chapter 5). Thus, for any product the total material flows activated is calculated as tonnes of materials of different categories. In order to guarantee reproducibility, a number of individual standards and conventions are being introduced, currently being compiled in the MAIA handbook ([27]).

Mips is analogous to usual efficiency measures in that it has the same structure of a share between inputs and results but is very different in that it links two well-distinguished objectives (nature preservation on the one hand and well-being on the other) and constitutes an intermediate objective expressing the extent to which they are (or must be) reconciled. The lower the *mips*, the higher the amount of services obtainable from a given displacement of natural resources and / or the lower the displacement necessary to obtain a given level of services.

In a nutshell, *mips* relates the material inputs necessary for the production, distribution, use, redistribution and disposal of a given good to the end-user service provided by that good. This allows comparisons among different yet functionally equivalent products; for example, the average "material burden" associated with travelling from A to B by car can be compared to that associated with the same transport service enjoyed on a train.

Material intensity and flow accounts are analytical tools to illustrate how much material and energy flows through the economic system at the product, company, sectoral, national, regional and international levels. These tools are aimed at quantifying the efficiency of economic operations, such as determining the material and energy flows per unit of service (*mips*); at addressing equity questions, such as how much material and energy is used by whom and how it is distributed; and at illustrating global patterns in the origin and movement of material and energy. Finally, they should lead to action: the *substitution* of a certain amount (including "rucksacks") of any specific material with a lesser amount of another one, while delivering an equivalent service, is regarded as a key task for innovative research in new and improved materials.

4.1. Measurement of Material Flows and the Resource Intensity of Economic Outputs

As explained, the material input analysis (MAIA or MIA) of any economic output comprises all inputs of materials, defined as the mass of raw materials influenced by anthropogenic use (ores, minerals, etc.), differentiated by five categories and summed up in mass units (kg). Included are all materials which had to be moved in order to extract or harvest raw materials or to build infrastructures, e.g. non-saleable production (overburden, gangue etc.), drainage water and felled trees. Not included, however, are the material flows associated with the other production factors, i.e. finance and labour, that have been activated in order to create the process analysed.

For example, to carry out the material input *MI* -analysis of a passenger car, first all materials actually found in the product

Material Flow Analysis and the Environmental Impact

In order to quantify the environmental pressure of human-induced material flows, two basic questions are of primary interest:

1. How to indicate the specific environmental pressure caused by material flows that have already been evaluated as "harmful"?

Environmental policy has evaluated certain themes to be of prior importance (e.g. global warming). These can be related to the associated material and substance flows (e.g. fossil energy carriers and CO_2). Specific pressure indicators can be based on known cause-effect relationships and operationalised on the basis of test data (e.g. global warming potential, GWP). All existing knowledge about the property of certain materials and substances should be used to derive data on the specific impact per unit of material or substance flow. Material flow accounts can then be used to monitor the actual pressure in terms of material flow in tonnes per year. This, however, only works for substances with a known *specific damage potential*.

2. How to indicate the environmental pressure of material flows in a general way, if it is not (yet) known specifically?

This question refers to the *unspecific disturbance potential:* it seems to be the usual case rather than the exception. For most of the toxic, nutritional, mechanical, structural, and physico-chemical effects associated with material flows, a standardised method for a reproducible quantification does not exist. Moreover, from a scientific point of view it is generally impossible to foresee all possible impacts of human-induced material flows that may be of relevance in the future. Furthermore, in most cases there is only information (albeit limited) available about the material flows themselves, and not about their specific environmental impacts.

Irrespective of the unknown impacts per unit of flow, any flow account may be interpreted in the way that the disturbance potential (an unspecific pressure) will increase with the amount of the accounted flow. Thus, it will indicate the current situation of environmental pressure.

"passenger car" would have to be counted. These materials would then be traced back to the raw materials extracted / harvested, such as the extraction of iron ores, including non-saleable production. Then, all materials would be counted which are not found directly in the car, but which have been necessary for production and use (e.g. gasoline and oil including materials which have been moved for their extraction such as water for the extraction of crude oil). Also water for cleaning purposes or tools used in a repair shop would have to be considered at this point. Finally, materials used for the transport of ores or for any intermediate transport by truck would be counted, including materials consumed for energy generation. For calculating the material flows associated with 1 kilometre of car transport, the total material flow would be divided by the average number of kilometers driven over the lifetime of the car under consideration. In a similar process, the *MI* of the transport infrastructure would be added (roads, filling stations, service points, administration etc.) ([29])

As the amount of data for any particular product or service may be extremely high, it would be helpful to develop a database, which would allow the efficient calculation of the *mips* of any given product or service. Setting up such a database is considered a key task for the future work on material flow analysis.

4.1.1. Definition of "Ecological Rucksacks"

The "ecological rucksack" ([30]) results directly from the listing and accounting of all materials found behind a final product or a service, or any economic output in general, as described above. It is defined, in general, as the sum of all materials which are not physically included in the economic output under consideration, but which were necessary for production, use, recycling and disposal. Thus, by definition, the "ecological rucksack" results from the life-cycle-wide material input *(MI)* minus the mass of the product itself. Ecological rucksacks are calculated integrating the five main categories of material flows.

Besides all the material activated in the life cycle of a product or service, all materials are counted which were consumed indirectly for the production, packaging, operation or use (washing agents, water, fuels, etc.), maintenance (paints, cleaners, etc.) and repair (spare parts, etc.) of the output under consideration. In addition, all materials are counted, as far as possible, which were necessary for the production or operation and disposal of an output, in terms of materials consumed for energy generation and also the share of infrastructures (like transport, extraction, production, and disposal installations) including all inputs necessary for their construction, operation, maintenance and destruction.

Recycling, in general, refers to processes from which materials are provided so that they can replace raw or other materials in other processes. If materials are recycled (secondary raw materials), only the material input necessary to run the recycling process is counted as their ecological rucksack. The mass of secondary raw material itself remains with the rucksack of the main product of the original process and will not be counted again for the recycled product. All subsequent processing and manufacturing is allocated to the secondary product as usual, i.e. as is done for primary products. The secondary product will then have as its specific "rucksack," all material flows caused by the refining and processing due in the course of the recycling – an amount that in some instances has been demonstrated to be higher than that from the primary production process.

By-products are defined as any product resulting from a process that has not as its principle aim to produce them and which can substitute main products as inputs in further processes. By-products may become main products due to changing situations of markets, e.g. in the field of chemicals. The rucksacks of by-products are those input materials which have to be provided for further processing. In case the original process consumed inputs which related exclusively to the improvement of quality and, thereby, the better use of by-products, those inputs would be accounted for in the ecological rucksack of the by-product. The mass of the by-product itself is contained in the rucksack of the main product (for more details see the MAIA handbook).

4.1.2. Categories of Flows Analysed and their Composition

Material inputs are calculated and presented separately in five main categories:

I Abiotic (i.e. non-renewable) raw materials
II Biotic (i.e. renewable) raw materials
III Soil (agriculture and forestry)
IV Water
V Air

This basic differentiation already implies the rough distinction between non-renewable and renewable materials. Going into greater detail, it may be useful to set further differentiations, e.g. to exclude wood from primary non-managed forests from the category of "renewable materials". The same applies for water, e.g. deep ground water presented as a separate category (see below). The situation is, however, more complex in the case of soil. In general, soil is renewable by biogeological processes, but these proceed at rates which are usually at least one order of magnitude slower than processes induced by human activities, often leading to irreversible soil losses and degradation (e.g. erosion, salination, nutrient losses).

The next level of disaggregation reveals the following categories:

I Abiotic Raw Materials:
- Mineral raw materials (saleable production, e.g. sand and gravel, ores.)
- Fossil fuels (e.g. coal, oil, gas)
- Non-saleable production (e.g. over burden, gangue)
- Excavation (e.g. for construction).

II Biotic Raw Materials
- Plant biomass from cultivation (agriculture and forestry)
- Biomass from wild harvest (e.g. fishing, hunting, gathering).

III Soil: All soil moved at the earth's surface (i.e. all biogeologically formed soils containing at least 2% humus, e.g. agricultural land, pastures, forest soils).

IV Water may be differentiated either according to its origin or according to its use. Analogous to the main categories I and II, water should always be accounted for after its origin:
- surface water
- groundwater
- deep groundwater.

V Air or constituents of it, if it is physically or chemically transformed. Categories are:
- air for combustion
- air as raw material for chemical/physical transformations.

Besides this first and rough description of categories of material flows ([31]), a number of individual conventions have to be considered, which are described in detail in the handbook on material flow analysis, but cannot be elaborated here due to restricted space.

4.1.3. Classification Procedure

In practice, data collection for material flow analysis will proceed at the highest classification level, allowing data to be classified according to the main categories and subcategories of material flows (see page 18).

This is relatively easy for raw materials and for most semi-manufactured materials. In the case of highly complex materials, however, only an upstream analysis of individual constituents to the level of raw materials will permit the basic classification procedure to be applied. As a general rule, materials should not be classified at a higher level than given by the five main categories. An exception to this rule may be a comparative analysis of economic and material flow data on the level of national economies (e.g. kg materials moved per ECU of GNP; in terms of total materials without water and air, i.e. the main categories I, II and III) ([32]).

4.2. Material Flow Analysis of National Economies

As mentioned, the Material Intensity Analysis (MAIA or MIA) can be applied on several levels (product, firm, economic sector, regional or national economy). This chapter will emphasise applications on a national level.

4.2.1. Material Flow Balance

The objective of national material flow balances is to understand the material throughput of a national economy and its material exchange with the environment. In order to analyse the "metabolism" of an national economy one should account for the material inputs and outputs in total. Due to the "law of conservation of matter" the final amount of wastes and emissions is ultimately determined by the magnitude of inputs insofar as these inputs are not stored within the anthroposphere (i.e. national economy).

The domestic material flow account or material flow balance comprises the physical mass balance of domestic extraction from the environment, domestic deposition and release to the environment, imports and exports. Figure 4.1 shows the material flow account for Germany in 1991 where all material flows are included, on the right hand side, with the exception of water. The overview provides the following major points of information:

- The difference between inputs and outputs equals 0.8 billion tonnes (10 tonnes per capita). This amount results from the material that is added to the stock of infrastructure, buildings, etc. This indicates the physical growth of the German technosphere which is unsustainable*per se* due to the increasing loss of natural and productive land.

- Most of the domestic resource extraction is non-renewable. The domestic input of abiotic (= *non-renewable*) raw materials exceeds the input of biotic (= *renewable*) inputs by a factor of about 20 (based on fresh weight of the plant biomass from cultivation). As more than 80% of the German territory is already used for agriculture and forestry a significant increase of the share of renewable inputs will require drastic changes in technology leading to a reduction of non-renewable inputs.

- The input of renewables is interlinked with non-renewable flows. The input of biotic raw materials from cultivation is associated with an erosion level that surpasses even the dry weight of the raw materials. The erosion rate on agricultural land exceeds the natural rate of regeneration by a factor of 10.

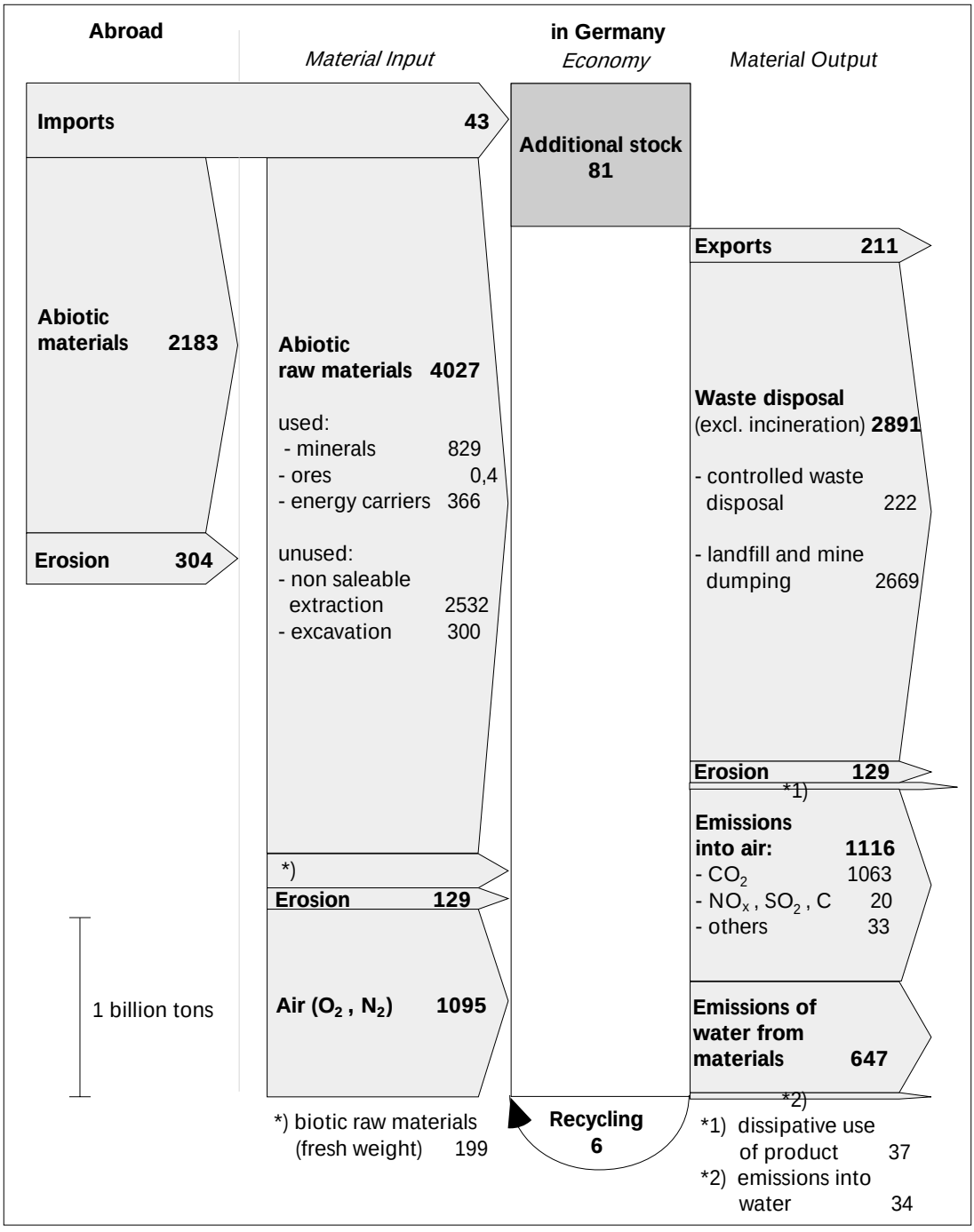
- A tremendous part of the abiotic raw material input remains unused. This is mainly due to the non-saleable extraction of coal mining. These masses are dumped without being used economically. Landfill and mine dumping (on the output side) exceeds the mass of all other waste disposals at controlled sites by a factor greater than 10.

- On the output side, it is interesting to note that CO_2 emissions into air amount to 1 bn tonnes. This is more than one-third of all waste disposal (excluding incineration), corresponding to about 13 tonnes per capita.

- Input and output are mainly determined by "throughput flows" which are released to the environment after short-term use. This applies to energy carriers, non-saleable extraction, excavation, most of the biotic raw materials, erosion, air and water. "Storage flows", which are used for durable products and will be released on the output side with a certain time lag, represent a minor quantity. Building minerals, a certain amount of the ores, and part of the biotic input (e.g. wood) are examples of such durable products.

The major general information that can be derived from the material flow balance is the interlinkage of Material Inputs and Material Outputs of the economy. Every material

Figure 4.1. **Overall material flow account of the German economy (1991) including cradle-to-border flows (without water and air, conservative estimate) together with the production of the imports in the countries of origin.**



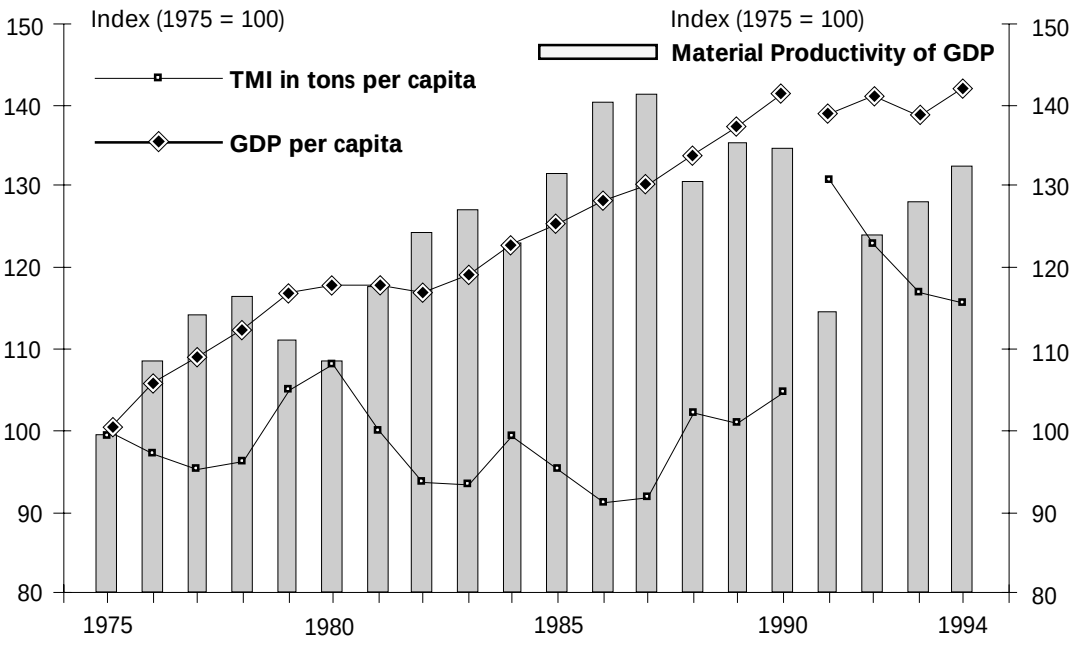
extracted from the environment will also sooner or later burden the environment on the output side. Any non toxicity-based pressure related to the outputs (releases to the environment, wastes etc.) can only be diminished successfully, if the input of primary materials to the economy is reduced.

4.2.2. Total Material Input

If the possible impacts of material flows induced by a national economy are to be evaluated in a global context (and this seems indispensable with respect to sustainability), then global material flows interlinked with the national production and consumption must also be accounted for. [34] In this case, the service unit for which all Material Inputs are accounted for consists of all economic activities within a national economy. The transnational extension of the domestic flow account is a necessary prerequisite in evaluating real progress towards sustainability.

Trends of total material Input, GDP and material productivity of Germany's GDP (since 1991, united Germany)

Figure 4.2.



Source: S. Bringezu, Material Flow Indicators, In: B. Moldan, S. Billharz, R. Matravers (eds.): Sustainability Indicators. Report of the Project on Indicators of Sustainability. Series: SCOPE, No. 58, John Wiley & Sons Ltd., Chichester, pp. 170-180.

Indeed, the activities of the German economy are associated with a huge resource extraction in foreign countries. In Figure 4.1, the left side shows those material flows that are interlinked with the production of the imports on a cradle-to-border basis. This data is based on conservative calculations using available statistics. It represents minimum values comprising mainly non-saleable extraction of mining and soil erosion by agriculture that burden the environment in the countries of origin. For that purpose, Material Input coefficients were determined for imported raw materials, semi-manufactures and final products ([35]). The coefficients for raw materials such as iron ore were calculated based on specific studies of typical extraction conditions in the countries of origin. Coefficients of semi-manufactures are deduced from life-cycle-wide calculations for various base materials such as steel based on German production technology which was assumed to be representative or at least a conservative estimate for industrialised countries. Material Input of final products (e.g. cars) was approximated based on the content of major base materials (e.g. steel). Thus, the result has to be taken as preliminary, whereas sensitivity analysis indicates that the order of magnitude will not be influenced by further detailed accounting.

One result of the preliminary account is that transnational material flows have nearly the same order of magnitude as domestic extraction from the environment (without water and air). Thus, the transnational material flows interlinked with the German economy cannot be neglected when monitoring the global burden of the national economy.

The **Total Material Input (TMI)** comprises national and transnational (i.e. global, induced by imports) material extraction from the environment. The TMI may be regarded as an integrated indicator that relates to the global environmental pressure associated with the physical basis of an economy ([36] [37]). No economy would work without yearly input of materials, either from domestic or foreign origin. Thus, TMI can be interpreted as an indicator of the environmental pressure associated particularly with an economy's production and consumption patterns. For practical reasons, TMI is confined to materials other than water and air.

TMI may be used as a basis to indicate the overall material productivity of an economy. The relation of GDP and TMI provides the material productivity of GDP. This indicator can be interpreted as a measure for eco-efficiency ([38]). However, increasing numbers of that indicator do not necessarily reflect a reduction of the absolute environmental pressure. Preliminary data indicate that the order of magnitude of TMI per capita

remained nearly constant from 1975 to 1990, while GDP increased more or less steadily (Figure 4.2). This resulted in an increase of the material productivity of GDP. TMI increased with the re-unification of Germany (due to lignite production in the eastern part of the country) but was reduced afterwards due to a convergence of technology. In 1991 TMI was about 90 tonnes/capita (excluding water and air).

The approximation of TMI in the time series was conducted assuming constant ratios of Material Input per product imported to the Federal Republic of Germany (based on 1991 values). In this case, final products have only been accounted using their own mass. Whereas the accounts have to be taken as preliminary, the data quality seems to be sufficient to indicate, at least initially, some main trends. The results indicate a possible decoupling of the global Material Input and economic performance. But the development of absolute environmental pressure due to the material flow basis of the economy is far from declining, a tendency necessary for sustainability.

Recently, the method of accounting TMI developed in Wuppertal has proved useful for international comparisons. In cooperation with colleagues from the World Resources Institute, the Dutch Environmental Ministry and the Japanese National Institute for Environmental Studies, TMI accounts for the USA, Netherlands, Japan and Germany were developed ([39]). The TMI of each of the four economies was rather similar, despite the fact that its composition varied considerably.

One may argue that any country is responsible for the environmental burden of its exports and that material flows should not be assigned to the importing country. Indeed, material-flow accounting allows the calculation of the global **Total Material Consumption (TMC)** of a national or regional economy also by considering those cradle-to-border flows that are associated with exports ([40] [41]). The preliminary accounts indicate an order of magnitude for the German TMC of 70 tonnes per capita in 1991 (materials other than water and air).

4.2.3. Allocation of Material Flows to Economic Sectors

In order to specify priorities for dematerialisation measures the overall account for a national economy may be allocated to the different economic sectors. Several rules exist to attribute TMI to the economic sectors relative to their economic outputs. First, the TMI of the whole economy can be attributed directly to several sectors (incl. private households) according to their domestic resource extractions and imports. As for these direct MI, the bulk of the inputs is usually concentrated on a few sectors, in Germany mainly coal (incl. lignite) and construction materials, with non-iron metals dominating the imports.

Another possibility stems from using input-output techniques that allow a re-attribution of the MI to the final product. The MI of the end product is much more even and complex, with no single sector's output dominating. In other words, the "points" of entry are much less diffused than the points of exit – a good precondition for effective policy regulation, as mentioned earlier.

The introduction of an input-output framework is an important step towards reaching the following goals:

- generating information about the "embodied material flows" of final demand;
- providing a linkage of material flows to economic activities, i.e. to analyse the economic determinants of material use and to assess the effectiveness of policies targeting their reduction;
- in a subsequent step, calculating the "embodied labour" of final demand in order to be able to maximise the labour market effect of any chosen (sustainability) policy. ([42])

And on a more technical level:

- combining information from different statistics (e.g. production and environmental statistics) into a coherent framework;
- establishing a structured information base that can be used to derive indicators for progress towards sustainability;
- distinguishing technological factors and demand factors, as clearly separate intermediate causes of materials' uses – and therefore as intermediate objectives of policy.

4.2.4. Possibilities for further applications

Limits to the current applicability of this kind of study are linked to the availability of appropriate statistical data. As already mentioned, the method can be applied, in principle, to any well-defined economic

system, be it a region, a state or a community of states. For instance, once the input-output statistics currently being developed for the whole European Union by Eurostat are available, it will be possible to perform similar applications at the European level. Provided the sectoral split is narrow enough, the accuracy of the method would surely benefit from the "internalisation" of flows among member countries, which are of course not "explained" in single-country applications. Direct *MI* figures will also be necessary, of course, in order to perform such applications; these also need to be systematically collected.

The application of input-output techniques to primary material inputs does not differ much from any other application of this methodology to the reattribution of primary inputs (including labour), to the final goods and categories of use which are directly and indirectly responsible for them. This allows comparison of the total material requirement (or job creation rate) of any given sector with its total requirement of other inputs, as well as with the total value-added "activated" by the final purchases of that sector's production. From these measures, interlinkage indicators for the vertically integrated sectors can be derived very simply, such as "resource efficiency" in terms of value production, or "labour intensity per unit of material use", expressing the trade-offs between economic and social objectives and the protection of the environment. ([43])

5. Eco-efficient Services: A New Concept of Service ([44])

Economic goods comprise goods and services. The concept of "service" is frequently understood to mean "non-material goods", whereas goods are seen to represent the reverse: they are "material services." While this concept of service is widespread throughout official statistics and manuals, it nevertheless obscures an understanding of the meaning of service in a sustainable economy, which presupposes an ecologically oriented goods production. In this way, goods can be seen as the medium through which certain services are performed. Through services they provide utility to consumers and serve as a means of production. Above all, a sustainable economy mandates a reorientation in the use of goods. The material value, the physical existence of a good is not what determines its economic worth, but rather its "use-value," the recognition that products as well as infrastructure perform services in both objective and subjective ways.

Goods therefore provide people with both a functional purpose and a set of services. Drawing on this new interpretation of services, one can conclude the following: the depletion of the environment can be largely reduced if goods which perform equivalent services, but with less material intensity, are used. This does not really entail relinquishing use-value and functional possibilities. Rather, those services that are supplied through the carrying media (products) are optimised, from an ecological viewpoint. Better still, customer services are demanded without an accompanying increase in the purchase of material-intensive goods.

To determine whether the purchase of a good should be substituted through an eco-efficient service, the material intensity as presented above can be related to the number of services units provided by the products. Here, a service unit is certainly an arbitrary setting. It attempts to relate the material input to a concept more objective than "utility" (the economists' favourite conception) but more general than the products themselves. Services can always be performed with various (sets of) products ([45]).

5.1. Types of Ecological Service Concepts

The purchase of goods can be understood as a change in the property rights of a product (property rights of disposal, use rights, right of profit acquisition, right of third-party exclusion). Obviously, these rights can be divided between the supplier and the user / demander of a service in various ways. For example, all rights of disposal can lie with the user, as in the case of the purchase of a good, or almost all rights of disposal (except for a restricted use right) can remain with the supplier, as in the case of a "pure" service. Between these two ends of the spectrum, a wealth of other variations exist. Rather than depicting all of these possibilities, we will summarise three ideal types known in the literature as "concepts of ecological service."

1. *Product-oriented ecological services*: These services are additional deliverables offered by producers as supplements to goods – either as a self-standing offer or as an instrument to promote sales. *Advice given by suppliers* (e.g. on labels) concerning the use of the product can, for instance, optimise the use by the consumer, and *maintenance and disposal services* (guarantees for returns, recycling services, etc.) can facilitate the return of carrying media.

2. *Use-oriented ecological services*: These services do not have the performance as sales objects, but rather serve as mediators. "Leasing" enables the user to use the products as a carrying medium of the desired service for a restricted time, "sharing" refers to the joint use of a single carrying medium, and "pooling" entails (joint) access to the use of a greater number of objects.

3. *Need-oriented ecological services*: These services mediate between certain types of needs (e.g. mobility) and various alternatives to the satisfaction of these needs. For certain consumer goods (such as energy, water, fertiliser), *least-cost planning* concepts have been developed. In this way, suppliers finance the profitable savings investments of demanders, and the resulting profits are divided between the demander and the supplier. For demanded goods (and in the frame of outsourcing), *facility management* concepts have been developed. Here, the demander will take no part in the exploitation of the carrying medium, but rather the supplier does this himself and the demander

only sells the result of this activity (i.e. copying services, document development, etc.). In these operational models, the incentive for the supplier lies not in the optimisation of the carrying medium itself, but in the optimisation of the framework in which the user / demander invests.

These three examples of ecological services suggest that it is indeed possible, with both product and service specificity, to investigate the optimal structure of property rights in order to reduce material intensities and at the same time to maintain and possibly even improve the level of service. The structure of property rights as a "pure" service, we can see, does not translate to both product and function in the same way.

Individual use is therefore efficient whenever the actual degree of use corresponds to a product's use potential. It is well known that the level of care given to service equipment depends in large part on the ownership situation: the condition of many railroads throughout Germany or the condition of houses and factories in the former East Germany clearly illustrates this. Nevertheless, community goods or leased equipment certainly must not be intentionally damaged or destroyed. Consider rental cars or leased construction equipment. The care taken when dealing with goods is undoubtedly primarily a question of group self-understanding and above all depends on the proper safeguarding of use-rights as well as the timeframe suggested above. We can now come back to one overall topic: to combine ecological and economic sustainability (see Chapter 1).

5.2. Service Units

As to the extent of this dematerialisation, we propose an intensification of resource productivity by a factor of 10. This means that in industrialised nations, materials (or material flows) that are mobilised for economic purposes need to be reduced by 90% over a period of 50 years, in order to realise a 50% reduction in materials (material flow). To achieve this aim, the factor 10 relates to the life-cycle of economic performance and is not related to specific types of industries or materials. Such an approach, together with ecological structural change in the direction of eco-efficient services, leads to a new orientation of processes, goods and infrastructures that is capable of performing the necessary service requirements with reduced expenditures of energy, area and materials.

The realisation of this solution can only be achieved by combining a variety of strategies:

- *Efficiency strategies*, "more services from less resources", seeking less resource intensive technical and organisational solutions for the satisfaction of needs, promoting the increase in resource productivity. Organisational efficiency measures providing constant levels of services from less resources include leasing, sharing and pooling.
- *Sufficiency strategies*, "more well-being from less services", refer to cultural innovations more than to technical ones. They necessitate the elaboration of alternative models of prosperity including new concepts for the use of products, infrastructures and services.
- *Environmentally sound product development*: Product development that is geared towards the creation of long-lived and easily maintained goods would contribute positively to the reduction of material intensity. Products could also be developed and used in a way that leaves little contradiction between their actual and technical / economic lifespans, thereby reducing the goods, sensitivity to rapidly changing trends. With environmentally sound product development, technical arming and conversion should also be linked with less energy and material expenditure.

5.3. *Mips* as a Business Tool

Besides being an analytical tool, *mips* can also be applied as an instrument to establish a system of resource management. On the company level, any such system, based on the *mips* concept or at least including it, should help companies to make pro-environmental decisions faster, more reliably, more comprehensively and cheaply, i.e. in an environmentally as well as economically sound way. ([46]) Material input calculations can be performed in analogy to a company's system of cost accounts. ([47]) The first results of the life-cycle of consumption of material inputs are available for certain products and materials such as steel, aluminium, paper, orange juice, textiles and transport infrastructure. ([48]) *Mips* has also been discussed as a way of implementing a system of environmental management according to the European Union's eco-auditing legislation, and practical suggestions have already been made for low *mips* products and eco-efficient services. ([49])

6. Material Flows and Sustainability Indicators

Indicators help to measure changes and progress in an increasingly complex field of private, commercial, and political decision making: policies towards sustainability. Agenda 21, Chapter 40, ([50]) demands the development of indicators; EEA, Eurostat, UNStat, OECD and national governments are working on it. For the sake of transparency, the political decision-making process must be supported by the availability of a set of *simple and directionally safe indicators*, applicable to different policy scenarios and thus contributing to the comparison of their potential outcomes. So far, however, the development of reliable (i.e. directionally safe) performance indicators that permit operationalisation and help steer the ongoing structural change towards sustainability is still far from satisfactory.

> "Environmental Indicators enable a clear information exchange regarding the issues they address. They serve to supply information on problems enabling policy makers to appreciate the seriousness of environmental problems, they support policy development and priority setting by identifying key factors that cause pressures on the environment. Finally they serve to monitor the effects of policy responses and allow the public to follow and participate in the process, making it more accountable."
>
> *Domingo Jiménez-Beltrán, Executive Director, European Environment Agency*

A basic problem is the fact that all indicator development unavoidably includes value decisions (e.g. by choosing "relevant" phenomena or by setting target values),([51]) which are not scientific, but which fall in the competence of the public and its representatives. This is just as true for *mediation between different values*, done by assigning differing weights to different elements to be integrated in the process of data aggregation, since this implies making decisions about the relative importance of several environmental factors. At the end of the day all these indicators have to be the result of the political process. ([52]) This implies taking extreme care in the construction of *mixed indices*, which combine indicators derived from the analyses of different phenomena and integrate them into one simple indicator or index. Although improving communication, such indices all too often risk being meaningless or even misguiding. This refers in particular to methods of assigning an overall "total value" to all kinds of environmental impacts (or to defining the total economic cost of all the damage caused). All these practices substitute the complexity of reality with the complexity of the methodology without providing too much additional insight or transparency.

However, the linkages must still be taken into account: even dematerialisation as a key measure taken to reduce the pressure on our environment cannot stand alone but has to be linked to the state (e.g. reduction of waste and emissions), to the economy (e.g. impact on growth) and to social concerns (e.g. impact on employment), if its impact on sustainable development is to be assessed. For this reason we propose developing a limited set of linked indicators, instead of one overall index. The indicators will be derived by systemic reasoning instead of data aggregation.

6.1. Established Indicator Systems

Initially, it has to be said that with regard to the different functions of indicators (policy development, enforcement monitoring, state analysis), there is probably no single optimal system of indicators. Instead, different but mutually reinforcing systems may prove to be the more appropriate solution, each covering one (or several) functions in the most appropriate way.

The three main purposes of the use of indicators, as well their requested qualities, are as follows:

- Summarising analysis: all indicators must be based on world-wide recognised methodologies and valid data. The number of such indicators will usually turn out to be comparably high, in order to cover all relevant aspects in sufficient detail. A well-known example under development is Eurostat's Environ-

mental Pressure Index project. ([53])
- Political guidance: indicators should provide links with players, causes and instruments. A limited number is necessary in order to establish a proper link to policy decisions arguably; it should be less than 10.
- Communication: vivid, easily understandable indicators are needed. However, there should be as few as possible, and possibly only one as a central com munications tool. In economics, the GNP serves this purpose.

For these purposes, a number of indicator systems have been established at the macro level. However, we consider material flow analysis an important amendment to the existing systems.

The OECD's Pressure-State-Response (PSR) approach for Environmental Indicators

The dominant indicator system in the international debate is the *Pressure-State-Response (PSR)* approach as proposed by the OECD ([54]) and shared (although partly modified) by other international agencies, like UNstat or Eurostat. Well-known modifications include the UNDPCSD's DSR (driving force-state-response) approach and the EEA's DPSIR methodology (driving force-pressure-state-impact-response). Regardless of the modifications, they share the basics of the PSR approach:

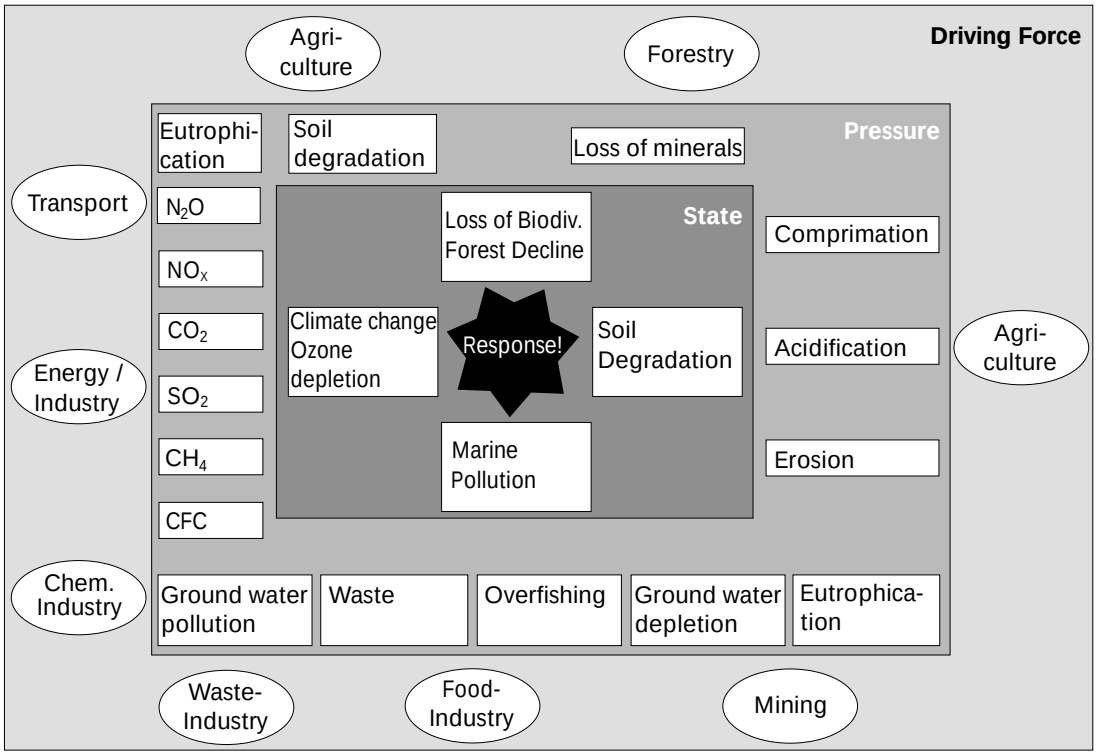
"The PSR framework for indicator development is based on the concept of causality:

- Human activities exert pressures on the environment.
- These pressure change the quality of the environment and the quality of natural resources (the 'state' of the environment).
- Society responds to these changes through environmental, general economic and sectoral policies (the societal 'response'). Thus societal responses form a feedback loop to pressures through human activities. Indicators may be developed for each phase in the framework." ([55])

This approach, however, inherits some, rather serious structural problems: ([56])

- The real world actually involves considerably more complex causal chains or webs than a linear P-S-R approach or its modifications can reflect. Consequently, neither a direct conclusion from pressures or impacts to states nor the deriva-

Schematic interaction of factors in a DPSIRsystem Figure 6.1.



Source: J. Spangenberg

tion of responses from states, its mechanisms and actors can be clearly defined.
- The structure of data available and the indicators based upon it is the result of questions asked in the past, so it only rarely sheds light on questions not based on past problems. Consequently, the focus is on predetermined environmental stresses which appear to be of major (political) concern at any given moment.
- In terms of resources, only the remaining, commercially exploitable physical stocks appear to be of interest, as opposed to the total activated material flows (a consequence of resource eco nomic thinking instead of environmental thinking, which focuses on physical flows).

Deriving responses from the selected states, i.e. the symptoms and episodic events, necessarily results in the development of (short-term) curative politics, preventing the development of cause-oriented approaches. In this respect the PSR approach and its modifications reflect a kind of political "end-of-pipe thinking" and thus cannot fulfil the requirements of proactive environmental policies.

Figure 6.2. **Environmental reporting with disturbance potential indicators**

A Proactive Input Based System of Environmental Sustainability Indicators

Resource consumption	Sustainability gap	Progress in the reporting period
Material • Material extraction (mio t/yr) • Share of renewables (%)		
Energy • Primary energy consumption (PJ/yr) • Share of renewables (%)		
Water • Water extraction (bio m³/yr) • Share of groundwater (%)		
Area • Development of infrastructure area (%/yr) • Development of undisturbed areas above a minimum size (%/yr)		
Soil • Erosion (t/ha/yr) • Loss of micro nutrients (t/ha/yr)		

In the EEA indicator system, ([57]) however, *driving forces* are recognised as distinct from *pressures*. Here, driving forces refer to economic and other societal developments, including some aspects of consumption as such, which may contribute to pressures like emissions, disturbance and so on, resulting in a *DPSIR system of indicators*. Since these latter categories fit particularly well with the approach proposed in this study (material flows as disturbance-potential indicators), we will follow the categorisation proposed by the EEA ([58]) when developing our proposal on how to amend the existing system of indicators.

However, some of the basic problems mentioned above are only partially solved with the DPSIR system introduced by the EEA: it gives only limited emphasis to input factors, although in addition to indicators of energy consumption, land use and water use, it includes one indicator on minerals consumption.

6.2. The Proposed Amendment

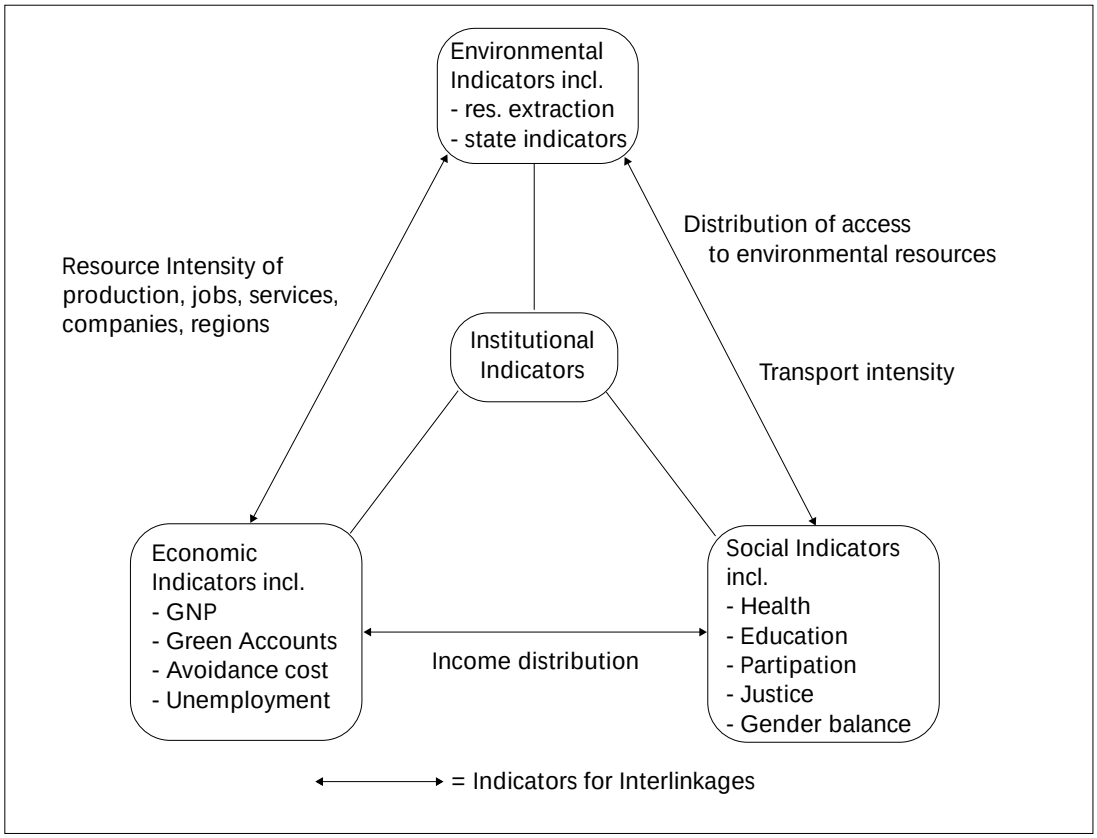
6.2.1. Proactive Indicators

Since designed for a certain purpose, proactive indicators cannot focus on symptoms or damages, which would only permit an ex-post analysis, but concentrate on the underlying trends in order to deliver ex-ante predictions of forseeable problems. Furthermore, they need not only meet scientific criteria, but also fulfil communicative and steering needs. While current approaches to the need of developing response indicators reflect (national) environmental protection policy priorities – which in themselves change over time – as well as administrative procedures already in place, it is our goal to develop indicators which:

- can be used to drive policies;
- are directionally safe and reliable in the long term;
- help to identify policy options and future administrative initiatives best suited to yield the desired results in a cost-effective manner.

Our main goal in this is to support the development of practical long term economic policies which minimise ecological impacts from mankind. In line with the considerations on environmental space, material flows and sustainability outlined above, we therefore propose to:

Sectoral and interlinkage indicators Figure 6.3.



- Base the assessment of the "environmental space" available to every human being ([59]) on the maximum global flux of resource extraction possible without deteriorating the global environment;
- Set standards for nature protection and land use regarding the main pressures for biodiversity instead of developing quantitative indicators, since the loss of natural areas and biodiversity are important but hardly quantifiable environmental damages;
- *Reach international consensus on global resource input reduction targets which would also yield corresponding decreases of undesirable outputs (emissions, effluents, waste). Product dematerialisation will reduce waste generation as well.*

The respective reduction targets for physical throughput would have to be set according to best available information (BAI) / best available data (BAD). These would then form the backbone of a system of directionally safe normative environmental indicators.

"Material" is understood to comprise abiotic and biotic material, the latter here being labelled "renewable". Air consumption should either be calculated separately or derived from fossil energy consumption.

Combining targets and indicators permits one both to measure distance to target, and to evaluate progress, making of the proposed indicators a set of environmental performance indicators as announced earlier. Based on a simple reporting sheet, this approach could be used to improve environmental reporting and communication on measures, as well as to provide a proactive assessment of plans and policies. Disclosing their impact on land use, energy and material consumption, before the decision is taken to the public at large, would allow for better informed decision making and consensus building using a shared set of information provided and comprehensible to all stakeholders. In addition, this obligation would enforce a major retraining, and (hopefully) a rethinking, for the staff members preparing such decisions, so that environmentally relevant policy impacts would have already been taken into account when alternatives for the final decision are selected.

The figures given so far for material input (*MI*), energy and land use relate only to the average resource use of a national economy

The indicators listed here are developed to characterise the dynamics of the development towards/ away from sustainability for an ecosystem, a region or a nation.

Indicators like GWP1, ODP2, acidification potential and eutrophication potential will be needed to additionally describe the state of the environment as well as some main pressures on environmental quality.

and are not to be understood to apply evenly to each economic sector, to all companies or cities, or to each consumer.

6.2.2. Interlinkage Indicators

Obviously, environmental indicators need to be linked to economic and social factors, in order to be developed into a system of *interlinkage sustainability indicators*, i.e. in order to properly address the inherent dynamics of our societies and economies as well as the quality of life to its citizens. This next step is also a prerequisite to developing a set of indicators with an improved policy-steering capacity. Broad societal consensus is required to provide implementation, sanction and thus, governance options, which is not necessarily implied by environmental target setting alone.

So far we have proposed limits to the extraction of resources from the environment, with the total material input *MI* (including energy) per unit of economic activity (e.g. GDP) for a given national economy as *environment-economy interlinkage* indicator. ([60]) Additional indicators fitting to the material flows and environmental space could then include:

- Distribution of access to resources, a *socio-environmental interlinkage indicator*, the target being equal access (on a per capita basis);
- Transport intensity as a *socio-environmental disturbance indicator* which not only reflects energy, material and land use by the transport system, but also social aspects like travelling distances and the corresponding shortage of private time spent with friends or family;
- Income distribution could serve as the key characteristic (for poorer countries or regions, the income level will also be crucial) for the link of the economic and the social dimension.

Other important characteristics of a sustainable economy and society, like the innovative capacity of economies, and the future character and quantity of labour will have to be characterised by economic and social indicators, which are not considered here.

6.2.3. Integration into the PSR/DSR System

It is our understanding that the system of indicators proposed here is not an alternative to the dominating PSR / DSR / DPSIR system, but rather a possible amendment designed to overcome the existing weaknesses described earlier. Hence, the environmental indicators proposed so far have to be integrated into a DPSR system of environmental indicators:

driving force	=	resources used / extracted, removed from their natural sites
pressure	=	increasing amounts of waste and entropy
state	=	overload of sinks and depletion of stocks
response	=	target values, quantification of the sustainability gap

Based on the above-mentioned reduction needs, and on some common sense cause analysis, an integration of material flows

Table 6.4. **A proactive DPSR system (inpact left out, specific to substances)**

	Driving Force	Pressure	State	Response
Energy	energy intensive growth	increasing CO_2-emissions	climate change ante portas	- 80% consumption
Material	material intensive growth	increasing materials extraction	non-quantifiable damages	- 90% throughput
Land use	CAP, Commodities trade	erosion, fertility losses	% degraded, % pasture, % farmland	-30% (sustainable agriculture plus end to land imports)
Transport	globalisation, growth	urban sprawl, congestion, noise	NOx concentrations, forest decline	ca. -50% (?) transport
Income level	State of development	poverty	% malnutrition	double for South
Income distribution	socio-economic system	dissatisfaction, unrest	access to schools, health service,...	redistribute fairly

measurement and sustainability targets into the DPSR system could look like Table 6.4 on page 28 (no impact assessment indicated).

Our set of response indicators is directly developed to reduce the main pressures identified (and the driving forces behind them) and thus is in a better position than usual systems as regards policy guidance. On the other hand, since our approach leaves out any analysis of the state, for environmental reporting purposes (i.e. for the efficiency control of measures proposed) it must be used together with a description of the environmental situation like the one provided by the DPSIR system. This analysis might lead to readjustments of the targets and tools chosen and is an instrument in its own right for monitoring the development towards sustainability. Both systems are mutually reinforcing and complementary. Rather than competing, they should be integrated into a common system which then would have improved analytical as well as steering capacities.

Thus, the system of indicators we propose is mainly a PR system; the state is not decisive for the responses proposed. The limited number of indicators makes it a handsome tool for decision-makers in politics, administrations and business, and the simplicity of the basic principles as outlined here makes it a useful tool for communication purposes as well (in this sense, again a PR system). Admittedly, it is rough, but even the best computing powers and cost-benefit analyses never indicate a “true” or “objective” direction for decision-making. Finally, since it is based on best available data, it can be adapted and improved according to the newest results of empirical science.

7. Economic Aspects of Sustainability and Dematerialisation

In order to understand the reasons for the double failure of our economies with respect to environmental and social sustainability, a brief look at their underlying economics will be helpful. Mainstream economists today consider the economy as a system which

- has a circular flow of income and output,
- is self-renewing,
- and self-feeding.

However, the *circular flow of income* (business income, investment, production and salaries, sales and individual consumption, which are in turn income to business again) is maintained by *linear flows of resources* such as energy and materials. All recycling activities, besides causing significant material flows and energy consumption themselves, cannot overcome the laws of Thermodynamics, according to which degradation by use is unavoidable. Recycling is necessary, but is a limited approach to dealing with the problem of making the economy sustainable (for instance, CO_2 cannot be recycled into energy, used pesticides and irrigation water cannot be regained). According to the same laws, each of these flows is inevitably linked by entropy, i.e. environmental disturbance potentials. Consequently, the level of dematerialisation needs to be set as a science-based policy target.

Once this has been done by giving a directionally safe, quantitative answer as we have done above, we can answer the questions about the corresponding social and economic costs of different alternatives (including the cost of inaction), and correspondingly, which policy strategies are acceptable from an economic point of view. Furthermore, the cost calculations will provide important background information for the citizen's decision as to which policy proposal he finds politically acceptable.

The *operationalisation* of the concept of sustainable development – i.e. the normative implications of the various approaches – which can be found in economic literature vary enormously: from the idea that not much has to be done, to the conviction that it is necessary to change our attitude towards the material comforts of the western way of life and to strive for sufficiency. We are inclined to accept the latter, less optimistic but more science-based prescription, for analytical reasons. Also for a simple precautionary principle, according to which when the situation is complex and not all consequences of human action can be fully predicted – as is certainly the case with environmental problems – minimal risk should be accepted. As a neo-classical economist would put it, we are very much inclined to extreme risk-aversion in the matter.

7.1. Limits of Today's Environmental Policy and Economics

State-of-the-art policy has its theoretical background in "standard" environmental economics. This concentrates mainly on allocational aspects and tries to integrate the environment into the neo-classical framework, where environmental effects are seen just as side-effects (externalities) of the functioning of an economic system which is otherwise conceived as basically closed (the circular flows mentioned above); on the contrary, interactions with the environment should be recognised as a built-in characteristic of the economy, which is fundamentally an *open* system. ([61])

Economists, particularly from the newly emerged school of ecological economics, are trying to integrate knowledge from natural science (especially environmental sciences) into economic thinking; they stress the dependence of economic activities on the natural environment as well as the irreversibility of the environmental effects of these activities. ([62]) The profound structural change necessary for sustainability also requires a theory of dynamic economic evolution, which, so far, is not being dealt with sufficiently by either environmental or ecological economics. This gap can be filled with the application and development of insights provided by so-called evolutionary economics and institutionalist economics. ([63]) In these approaches, the capacity to steer our complex and dynamic world, with respect to both ecological and economic systems, is seen as even more critical than in simple neo-classical textbook models.

In the theoretical and political debates on environmental policy, the necessity of a mix of different policy measures comes more and more to the fore. In other words, the promotion of appropriate property rights, market-incentive solutions such as the use of taxes, subsidies and certificates on the one hand and command and control measures on the other, are seen as complementary rather than substitutive. ([64])

7.2. The Economics of Dematerialisation: An Evolutionary Path Towards Sustainability

The limits defined by the sustainability objective constitute general boundaries, within which the allocational and distributional issues remain the primary concern of economic policy. More importantly, within these limits as few restrictions as possible should be imposed on the self-organisation and innovation potential of firms in the market economy. The dematerialisation approach, in shifting the emphasis from particular activities and specific regulations to general objectives, is better suited to fulfil the latter requirements. The fact that the reductions mentioned above are to be achieved as the overall result of economy-wide structural and technological change indicates the great flexibility of the strategy; it also leaves the policy-maker free to pursue objectives other than sustainability. Some activities may even expand the use of natural resources, provided others reduce them sufficiently.

We do not think of dematerialisation as some optimal policy in the traditional economic sense; that is, one that maintains the economy on a narrow and precisely defined path on which the best possible outcome for society is realised. Rather we think it is necessary to keep economic development within the "guard-rails" of the environmental space. These guard-rails define an evolutionary corridor towards which the economy can be directed by "artificially" introducing economic scarcity into the market system, where ecological threats are not automatically transformed into market incentives and disincentives. These guard-rails should be as transparent as possible and fixed in advance for a considerably long run, to provide the economic actors with the certainty they need, especially important when adapting to changing conditions.

7.3. Some Instruments of Dematerialisation ([65])

To implement any dematerialisation policy the inertia of society and its institutions has to be overcome (as opposed to the inertia of the ecological system, which is beyond our reach). One key element for this will be the price mechanism, which, as outlined earlier, is a perfect tool for dematerialisation politics.

All policies and activities which tend to change people's minds and attitudes have a tendency to go against freedom of choice and would not be effective. However, it is evident that public awareness campaigns, civic education and advertisements are widely used in real policies and economies, and are equally important in determining behaviour. The possibility exists of influencing the path of socio-economic evolution without restricting individual choice, but rather by promoting the introduction of more environmentally friendly alternatives, currently unavailable, and by spreading ecological consciousness and knowledge. *Mips* itself could serve as an (in)formative instrument, as a clear and simple measure, a single, unambiguous figure indicating nature's dissipation. It could be communicated to the end-user in the same way as the price is, so that a well-informed decision can be taken.

An ecologically inspired reduction of material flows requires a combination of market instruments and direct regulation. In this approach, regulation is not considered an alternative to market instruments; instead, both are regarded as complementary and *mutually supportive*. Also, changes in property rights would induce economic agents (households and firms) to use fewer natural resources.: for example, consumer durables and investment goods could remain the property of the producer or be bought mainly by firms that lease or rent them, instead of being sold to consumers (as is normally done these days, where property is often perceived as a *conditio sine qua non* of use). These firms would clearly have an incentive to increase the life-span of the product, to reuse it, and to enable recycling to a greater extent than is now possible.

An ecologically inspired tax reform would aim to shift the tax burden from wages to ecologically problematic materials and onto energy carriers (especially the latter). Ernst U. von Weizsäcker, for example, proposed to increase

prices for energy, material resources, waste and water by 5% per annum over the next 40 years. ([66]) The basic idea of such a long-term price increase is to influence both technical progress and the structure of consumer behaviour and other processes which generally change very slowly. Also material flows, as defined in the *mips* concept, could provide an appropriate tax base for ecological tax reform. ([67]) Financial incentives in the form of subsidies are also very important. Some subsidies are used for environmental goals but many others have negative side-effects for the environment, such as current subsidies for agriculture, coal mining, or gasoline. ([68]) There are various rationales behind these subsidies, such as low production costs abroad, securing employment or supplying the domestic population. ([69]) A restructuring of subsidy policy in which greater weight is given to environmental goals without overlooking other objectives, could be designed according to the need to reduce the use of materials.

Quantity-related instruments, such as tradable permits, could also be part of a dematerialisation strategy. They constitute a particularly interesting instrument because of their potential to reduce material flows leaving to the competition between producers the task of promoting new concepts of use, product life, and recyclability. Despite their many theoretical advantages, tradable permits are so far rarely used in Europe. ([70]) Material input certificates could be developed, with a national or international authority in charge of fixing the amount of extraction compatible with sustainability, while allocation and pricing of the various resources are left to the market process. ([71])

Whatever the mix of these instruments in pursuit of dematerialisation, regulations aimed at reducing specific emissions will in some cases be necessary as short-term policies. Their use should be restricted to the necessary minimum, however, since they do not allow for enough flexibility in reaction to dynamic economic processes. Although these measures have been effective in creating new markets in the past, economic measures may be better suited to promote competition, as a procedure to create and identify new opportunities, to induce long-term technical change, or to provide incentives towards ecologically sound structural change.

The problems of dematerialisation clearly have an international dimension. An energy tax, an ecological subsidy policy or other measures aimed at dematerialising economies, need a consensus at least at European level. The more effective international competition is, and the more mobile industries are, the fewer international incentives exist for national economic policies to induce an ecological structural change. National environmental policies will, therefore, need increasing international cooperation in order to secure national initiatives necessary for ecological reasons.

8. The Scope of Application

In general, statistical data necessary to establish material flow accounts (MFA) are available in official statistics. They are, however, distributed widely among different publications. For example, data on non-renewable raw material extraction may be found in production statistics, data on harvest of renewable materials in agricultural statistics, data on water consumption and waste generation in environmental statistics. The main task of establishing structured material flow accounting is thus to combine data from a number of different sources a coherent framework. In order to proceed to the latter, the system of environmental statistics will have to be modified. Generally, it should be structured according to the information requirement outlined under "scientific data and data basis" and presented in a single, comprehensive publication. Such a system can be well in line with the *mips* concept, as recent experience of the German Federal Statistical Office illustrates. ([72]) Its work resulted in the first Physical Input-Output Table PIOT for Germany, referred to earlier.

Basic data for the European Union are also available in EEA and Eurostat publications (e.g. "Europe's Environment: The Second Assessment" and "Europe's Environment: Statistical Compendium for the Second Assessment"), as well as in individual publications. However, no information is available so far which allows inclusion of land use per sector in environmental reports. In this case, a number of basic difficulties have to be overcome. As for material flows, the integration of material flow analysis (MFA) into EEA reports would be an obvious, if ambitious next step, including the further development and application of material flow- based sustainability indicators.

The material flow research initiated by Eurostat does not focus on overall MFA of national economies, but on providing selected substance flow accounts for products and substances harmful to the environment. However, it does focus on the relation to activities of individual sectors of the economy. This focus results from an *a priori* setting of priorities for specific problems and corresponding substance-specific approaches. Alternatively, sector-specific case studies could illustrate the usefulness of material flow accounting for environmental reporting as well as for economic planning (as existing examples from product assessment to material flow-based environmental management schemes indicates). Some first examples of preliminary sector studies are presented in Chapter 9.

9. Case Studies

In this chapter we illustrate the use of the methodology by applying it to three economic sectors: energy, transport and construction. Whereas energy is well known as a key sector for environmental concerns, the construction sector is not, although it is one of the most relevant in terms of induced material flows. Transport is one of the driving forces of material consumption in our societies; the study shows that its material flows are of high relevance as well.

Table 9.1. **General overview of materials associated with the generation, distribution and consumption of energy**

Generation, Distrubution and Consumption of Energy				
Processes	**Energy sectors**			
Raw materials extraction	Fuelwood (2/2)	Hard coal Lignite Minegas (6/10) Peat (7/10)	Uranium pres (7/12)	Crude oil Natural gas (8/11)
physical tran-formation	Charcoal (?/?)	Coke Briquettes Other coal products Coke-oven gas (6/10 + 23)	Nuclear fuels (9/23)	Refinery products (10/23)
				Natural gas provision/-distribution (4/40)
		Blast furmace gas (16/27)		Refinery gas (10/23)
energitic transforma-tion	Generation and distrubution of electricity (3/40)			
Provision of energy for final consump-tion	Final consumption of energy * Consumption by the generating sectors * Industry (manufacturing) * Transports and other services * Households (and other final consumption)			

SIO = Systematic of production sectors in German Input-Output Tables

NACE Rev 1 = General industrial classification of economic activities within the European Communities

9.1. Measuring Progress Towards Sustainability in the Energy Sector (Case Study I)

Relevance of the sector

Energy politics is probably among the most sophisticated of sectoral economic policies, and has been recognised as a key element of environmental policy-making since the early 1980s. The need to save energy, realised during the oil crises of the 1970s, constitutes the first politically dominant input reduction strategy. ([73]) Overall, it was successful: at least in some countries and for some time, even an absolute delinkage of energy consumption from economic growth has been reached, ([74]) although relinkage has been reported recently. ([75])

However, the problem as such is far from solved: the IPCC recommendations referred to earlier imply a 75% reduction of energy consumption for Europe, but these estimates are based not on energy supply limitations, but on material flow reduction needs, in particular for greenhouse gases. ([76]) A material flow analysis of the energy sector can thus help identify priority areas for energy conservation as well as proposals for changes in the mix of sources by substitution processes.

Definition of the sector

The energy sector as a single entity does not exist. A number of individual sectors of the economy are involved in the generation, distribution and use of energy (Table 9.1). On the process level, energy is generated from: (i) raw materials extracted from the environment (if not “gratis-inputs” like solar radiation, wind, water, geothermal etc.), either directly from (i) or after (ii) physical transformation (e.g. fuels from crude oil) or (iii) energy transformation (e.g. electricity generated in fossil-fuel power plants). Thus, the sectors providing energy (iv) for final use may be other than those providing the raw materials for generating energy.

In this study, energy sectors involved in processes (i) to (iii), i.e. providing energy for final use, are taken into account on the material level (e.g. coal, gas, oil etc.) according to the NACE Rev. 1 classification ([77]) and the German SIO classification ([78]) for comparison.

Sources of data

In general, energy statistics published by Eurostat ([79]) were used to calculate material flows in the energy sector. Data relating to the 15 Member States of the European Union and the World total was obtained using supplementary information from United Nations Statistics. ([80]) In the case of Germany, data was validated by comparison with national energy statistics. Ecological "rucksacks" of energy materials were taken from the databases available in the Wuppertal Institute, Department of Material Flows and Structural Change. ([81]) The base year is 1990 as the reference year for common energy and emission scenarios and corresponding reduction targets.

Material flow analysis of different energy generation and supply systems

As a first step, the material intensity of primary fossil energy carriers has to be evaluated. Based on individual data for non-saleable production (overburden and extraction wastes) and water (ground water extraction by mining), considering both inland extraction and imports, this can be documented on a tonne (or m^3) per tonne basis for the consumption of hard coal, lignite, crude oil and natural gas in the EU 15 (Table 9.2). Data points out the high specific ecological "rucksacks" of lignite and hard coal. This primary data is used to calculate corresponding "rucksacks" of processed energy carriers like coke, briquettes, gasoline etc. by using raw material conversion factors. Thus, the material intensity of energy carriers for final energy consumption is obtained.

Data obtained for material intensity of primary fossil energy carriers (Table 9.2) is taken as a basis for the calculation of material intensity of any product converted from them. In the case of conversion of energy carriers by electricity generation, material intensities are expressed in tonnes per 1 MWh gross electricity generated (Table 9.3). In terms of fossil energy carrier (fuel) consumed and non-saleable production caused, lignite is by far the most material-intensive energy system, followed by hard coal. Water consumption is due primarily to the use of cooling water by power plants and, thus, does not show differences between the individual energy systems studied. ([82])

To evaluate material flows relating to the generation and distribution of energy in the economy, a stepwise approach was chosen (see Table 9.4).

Material intensity of primary fossil energy carriers, consumption in the EU15 — Table 9.2.

	t/t non-saleable production	m^3/t water
Hard Coal	2.67	1.80
Lignite	8.50	6.00
Crude Oil	0.30	6.34
Natural Gas	0.22	0.03

Material intensity of electricity generation systems, Germany 1991 (public supply) ([82]) — Table 9.3.

	t/1MWh gross fossil energy carriers	t/1MWh gross non-saleable production	t/1MWh gross Water
Hard Coal	0.309	0.825	66.197
Lignite	1.226	10.420	66.197
Oil	0.244	0.073	66.197
Natural Gas	0.202	0.045	66.197
Nuclear Energy	0.014	0.228	66.285

In general, material flows were accounted for on the basis of physical input-output calculations at several steps of energy generation and distribution. Thus, primary energy consumption (PEC) reflects the net amount of energy materials including "rucksacks" extracted from the environment within the European Union, plus the net-import and stock changes of processed energy materials. The final energy consumption (FEC) comprises all material flows related to either energetic or non-energetic use. From this, the emission-relevant energy consumption (ERC) is obtained by subtracting the non-energetic use. The ERC reflects all materials combusted for energy generation either directly as raw materials or as products derived from them (physical transformation), or for the generation of electricity (energetic transformation), including their ecological "rucksacks". Material inputs comprise fossil energy carriers, non-saleable production (e.g. overburden by coal mining), water (e.g. ground water extraction by coal mining or cooling water by power plants), oxygen (O_2) calculated by the emissions of CO_2 etc., and others (e.g. additives to gasoline). Material outputs are given by emissions to air (CO_2 etc.), wastes

Table 9.4. **Overview of the procedure for the accounting of material flows related to the physical energy balance**

ENERGY BALANCE OF THE ECONOMY

INPUT	**ECONOMY**	**OUTPUT**
Energy carriers (Products) Electricity (in t)	Net-Imports (foreign trade balance; stock balance)	Energy carriers (Products) Electricity (in t)
Energy carriers (Raw materials) non-saleable production Water	**Primary energy consumption (PEC)**	Losses, Wastes non-saleable production Water
	physical transformation (PT)	
Energy carriers Water Additives	**Final energy consumption (FEC)** Raw materials / Products	Losses, Wastes Waste water
Energy carriers Water Additives	non energic transformation (NE)	NE-Products Wastes Waste water
Energy carriers Cooling water O_2	**Emission relevant consumption of energy (ERC)** Raw materials / Products	Losses, Wastes Waste water Evaporation Emissions into air
	energic transformation (ET)	
	Final energy consumption after transformation (FECT) Raw materials / Electricity / Products	
Material Input (MI): * Energy carriers * non-saleable production * Water * O_2 * Others (Additives etc.)	**MI in kg/MJ (kWH etc.)**	Material Output (MO): * Emissions into air ** CO_2, NO, SO_2, CO * Dust, Ashes * Evaporation of cooling water ** H_2O from H content ** H_2O from H_2O content * Residues (S, N) * Wastes; Waste water

(e.g. ashes and slags), evaporated cooling water, waste water, and non-saleable production which is both an input and output material flow. The material intensity at any step of generation and distribution is given by the amount of materials moved in relation to the energy service provided (e.g. in tonnes per Gigajoule).

The primary energy consumption of the EU15 is characterised by about 20 tonnes of fossil energy carriers used to generate 1 TJ (Figure 9.1). In addition, about 100 tonnes of non-saleable production and about 100 m^3 of water refer to the generation of 1 TJ primary energy in the EU15. The latter is close to the global average whereas the former is even more favourable than the global average of about 30 tonnes energy carriers consumed per 1 TJ generated. Within the EU15, however, considerable differences exist. Greece and the former Eastern Germany exhibit significantly higher specific material inputs for primary energy consumption than the EU15 average. This is mainly due to their proportionally high share of lignite for electricity generation in PEC.

On the other hand, the picture does not reflect the role of nuclear energy with a relatively low specific material input, except for cooling water by power plants. Therefore, the proportional share of nuclear energy in PEC will be pointed out separately. Also, the corresponding share of lignite and hard coal as high material intensive energy sources will be documented separately. For the same reasons, high material intensity of emission-relevant consumption is also found especially in Greece and the former Eastern Germany (Figure 9.2). This is furthermore underlined by high specific inputs of oxygen (O_2) for combustion and emissions into air. In the total, Figure 9.2 gives a complete aggregated picture of the balanced physical input-output of ERC (if non-saleable production and water are counted both on the input and output side of the balance). For validation of the data, documented emission numbers for CO_2 by Eurostat have been compared and found to be in good agreement with numbers calculated here by using specific emission coefficients for a total of 20 individual energy carriers.

The role of nuclear energy, lignite and hard coal

If the target for nuclear energy in primary energy consumption, e.g. as proposed in the "Sustainable Europe" study, is a complete phase-out by the year 2010, the present contribution of nuclear energy to PEC shows the specific needs for reduction on the national and EU level (Figure 9.3). Whereas the absolute contribution of nuclear energy to PEC (in TJ) clearly documents where structural changes will have to take place, the relative contribution of nuclear energy to PEC within individual countries gives an impression of how significantly these changes will affect internal structural changes.

Whereas the overall use of fossil energy carriers will have to be reduced dramatically in a sustainable Europe, material analysis as presented in this study reveals that especially lignite and hard coal are associated with dramatically high material flows relative to the amount of energy generated. This points out a priority of reduction needs within the group of fossil energy carriers (Figure 9.4). As in the case of nuclear energy, the geographical location of reduction priorities becomes obvious by the absolute amounts of lignite and hard coal consumed. However, this picture is much clearer in the case of lignite than in the case of hard coal, where nearly all Member States of the EU15 are more or less affected. The percentage share of lignite to PEC points out that especially Greece and Germany will have to undergo dramatic structural changes in their energy system. For the latter, structural changes are already underway since re-unification in 1990. Again, in the case of hard coal all Member States of the EU15 will be more or less affected by internal structural changes in their energy systems. This supply-side shift is in line with CO_2 reduction (as expressed here in O_2 consumption) for sustainability targets of the EU.

Interpretation and policy applications

Reduction targets for primary energy use, fossil energy use and CO_2 emissions have been calculated for the EU based on the IPCC recommendations as quoted. Results presented in this study focus on the demonstration of interlinked material flows of energy generation and distribution systems. These material flows are expressed in tonnes per capita compared with final energy consumption in GJ per capita (Table 9.5). Thus environmental pressure caused by material flows due to energy consumption can be looked at in a comprehensive way. However, energy reduction scenarios may be validated the same way by calculating the resulting effects on interlinked material flows as additional environmental pressures.

Monitoring the relevant material flows interlinked with energy consumption, as presented here, can therefore represent a more powerful instrument for decision-makers to help them formulate effective policies for energy conservation and emission reduction measures. Because data presented here (Table 9.5) result from a number of disaggregated categories of material flows, the focus on individual aspects of energy consumption is not limited. That is, by using a more detailed model of material flow analysis, the results of political measures for energy reduction can be as well documented for the emissions of CO_2, NOx, SO_2, as for the withdrawal of groundwater by raw materials extraction from the environment.

9.2. Measuring Progress Towards Sustainability in the Transport Sector (Case Study II)

Relevance of the sector

Speed and mobility can be considered two of the key determinants of modern industrial societies, and transport is at the very heart of both. Although significant efficiency gains have been achieved over the last two decades, they have been overtaken by the overall growth of the transport sector. This growth has not been homogenous, but has been linked to significant structural changes: from rail to road, from public to private transport, from smaller to bigger (and faster) cars, from shorter to longer and faster trips (the number of trips per day and the daily commuting times have roughly been constant), from commuting to the dominance of leisure mobility.

Table 9.5. **Final energy consumption in the EU15 in GJ and tonnes energy carrier materiel per capita 1990**

	Population in 1000s	Final energy consumption in GJ/capita	Final energy consumption in t/capita	Non-saleable production	O_2 Input	Water	Emissions into air
EU12	**326646**	**92**	**3.7**	**9.2**	**9.7**	**315**	**13.0**
EU15	**363837**	**97**	**4.4**	**15.0**	**10,1**	**332**	**13.8**
Belgique/Belgie	9948	129	4,0	10.1	11.8	458	15.4
Danmark	5135	104	3.8	10.0	10.6	305	14.1
Deutschland (West)	63254	117	5.4	17.5	12.5	430	17,4
Ellas	10057	57	6.6	**44,9**	8.6	199	14.6
Espana	38805	57	2.4	9.5	5,6	206	7.8
France	56577	93	2.5	5.5	7.3	422	9.6
Ireland	3507	83	5.7	18.3	11.4	241	16.6
Italia	56712	79	2.7	2,9	8.3	197	10.8
Luxembourg	379	**365**	**11.1**	24.4	**29.7**	**100**	**40.0**
Nederland	14893	120	5.2	8.2	16.3	310	21.0
Portugal	9920	**40**	**1.5**	**2.2**	**4.2**	122	**5.6**
United Kingdom	57459	99	4.0	3.3	11.5	349	15.1
Österreich	7690	115	3.3	5.3	8.8	291	11.9
Sverige	8527	161	3.6	3,0	8.9	**607**	12.3
Suomi/Finland	4974	193	5.6	9.1	14.0	593	19.2
DDR	16000	126	***20.7***	***147.,2***	18.3	478	31.4
Deutschland	79254	119	8.5	43.6	15.0	440	22.9
World	5295176	57	2.1	5.5	5.2	117	7.1
EU15/World	0.07	1.71	2.14	2.72	1.95	2.83	1.96

Given this complex pattern, policies need to define cross-cutting quantitative targets in order to integrate efforts to achieve sustainable mobility. Sectoral material flow analysis can contribute to this and thus complement insights from life-cycle-wide energy consumption and land occupation analysis.

On the product level: Automobile or Auto*stand*ile?

A middle class car is a means of transport, weighing about one tonne, made from about 20 tonnes of material (plus three for the catalytic converter), with a maximum speed of 190 km / h and an average range of 500km, in order to transport 100 kg of human being, 50% of the trips being less than one km, with 80% urban transport at an average speed less than 15 km / h, for an accumulated use time of three to six months (0.5 - 1 h / d). Is this efficiency?

Definition of the sector

The transport sector itself may be defined by activities according to the NACE ([83]) description on the EU level:

Code 60: Land transport; Transport via pipelines
- Code 60.1 Transport via railways
- Code 60.2 Other land transport
- Code 60.3 Transport via pipelines

Code 61: Water transport
- Code 61.1 Sea and coastal water transport
- Code 61.2 Inland water transport

Code 62: Air transport
- Code 62.1 Scheduled air transport
- Code 62.2 Non-scheduled air transport
- Code 62.3 Space transport

Code 63: Supporting and auxiliary transport activities; activities of travel agencies
- Code 63.1 Cargo handling and storage
- Code 63.2 Other supporting transport activities
- Code 63.3 Activities of travel agencies and tour operators; tourist assistance activities
- Code 63.4 Activities of other transport agencies

However, a number of other sectors of the economy are directly or indirectly contributing to the material flows activated by transport. In general, there is a close link to the energy sector and to the building and construction sector. Thus, studying these two sectors will provide information about the transport sector (Case Studies I and III). On a broader level, economic sectors interacting directly with the transport sector will be considered as follows:

Code 23: Manufacture of coke, refined petroleum products and nuclear fuel

Code 34: Manufacture of motor vehicles, trailers and semi-trailers

Code 35: Manufacture of other transport equipment

Code 45: Construction

Code 50: Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel

In this study, material flows in the transport sector were classified by a practical approach into three main categories according to average lifetime (Table 9.6). The first category comprises materials which are consumed within one year, i.e. especially energy, soil excavation (for construction) and water. The resulting outputs to the environment are mainly emissions to air, waste and waste water. The second category describes materials and goods which remain inside the technosphere for a period longer than one year and no longer than about 10 years. These are mainly all kinds of vehicles including associated spare parts and wearing parts. The resulting outputs to the environment arise either after the total-use phase (e.g. demolition of cars) or during the use phase (e.g. dissipative losses to the environment from tyres and brakes). The third category comprises material flows related to the stock of transport infrastructure such as roads, railways, waterways and pipelines. These long-lived materials comprise mainly construction minerals and ores / metals on the input side. Outputs to the environment for the third category are considered to result mainly from stock decreases such as demolition wastes and dissipative losses from infrastructures.

Data sources

Data for energy consumption of the transport sector was taken from the same sources as energy data in general (Case study I). It was, however, validated by comparison with

Table 9.6. **General overview of material flow accounting in the transport sector.**

Transport sector			
Materials	Throughputs = 1 year	Longer lived goods > 1 year < ca. 10 years	Long-lived goods > ca. 10 years
Material inputs	Energy * Gasoline * Others	Vehicles	Construction materials * Minerals * Ores
	Excavation		
	Water		
Stock			Infrastructures * Roads * Railways * Channels * Pipelines
Material outputs	Emissions	Wastes	Wastes
	Excavation	Dissipative Outputs	Dissipative Outputs
	Waste water		

average fuel consumption values ([84]) relative to the magnitude of transport services reported for different transport means by official statistics. Data for the stocks and flows of transport vehicles was taken from the same sources. Data referring to the stock and flows of construction materials for transport infrastructure is not available from official statistics. In this case, an indirect approach was chosen to estimate the corresponding quantities. First, the stock of different transport infrastructure was documented in terms of lengths in km and average annual changes for the period from 1970 to 1990. ([85]) In the second step, material inputs and outputs relative to the stocks and annual flow of transport infrastructure in the European Union were deduced from data available for Germany in the Wuppertal Institute's database.

Infrastructure and use phase

The infrastructure for transport consists mainly of transport ways and associated buildings and installations. Under transport ways the following are considered in this study:

1. Roads: motorways, main or national roads, secondary or regional roads, other roads
2. Railway network
3. Navigable inland waterways.

The use phase of infrastructure has not been studied in detail up to now. There is some empirical data on lifetimes of infrastructure for navigation. However, further research is needed to establish a similar data basis for common transport infrastructure.

Definition of service units for individual and public transport of persons and goods

Physical transport service units provided by official statistics are in general passenger-km for persons and tonnes-km for goods. The former can be roughly converted into tonnes-km to get a total of transport service units in tonnes-km for persons and goods traffic. This results in a total of about 1,600 billion t-km transport performed in the EU15 in 1990 (Figure 9.5). By far the largest share of this is due to road transport, followed by rail, inland waterways, pipelines and air transport. In order to derive from these numbers indicators for environmental pressure, the specific material intensities of the transport systems were examined.

Material flow analysis of road, rail, ship and air transport

Based on energy consumption and interlinked material flows, the material intensity of different transport systems in the European Union was obtained in grams per tonne-km (Table 9.6). The picture clearly shows that air transport is by far the most material-intensive system, followed by road and, with a large gap, by rail and inland waterways. Total traffic reflects the individual contributions of the different transport systems and is close to material intensity of road transport.

A comparison of material intensity for all means of transport shows that the average of EU15 is close to the global average (Figure 9.7). However, material intensities vary considerably between the individual Member States of the European Union. Especially Greece and Luxembourg are characterised by material intensities of total transport which are far above the EU15 average. In the first case, a proportionally high share of road transport in Greece (about 85 to 90% of the total) is an explanation for this result (compared with about 70% road transport in EU15). In Luxembourg, however, rail transport holds the largest individual share of all transport of about 50%. In this case, numbers for transport service units may be underestimated in official statistics leading to

unusually high figures for material intensity of all transports. Clearly, the database for transport services needs to be harmonised on the European level for a reliable comparison of material intensities of individual transport systems.

An overview of material flows and stocks in the transport sector of the European Union (EU15) in 1990 is presented in Table 9.7. The largest share of material flows into the transport sector (input) is energy-related. Fuels and energy carriers for electricity generation by railway account together for about 2.4 billion tonnes of material inputs which are actually outputs to the environment as well in the same period. The second largest material flow of about 0.75 billion tonnes is the contribution of building materials to the increase in the stock of transport infrastructure. The latter was estimated to be in the range of about 140 billion tonnes, mainly stocked in roads. On the other hand, outputs from the stock of infrastructure in terms of demolition waste amount to only about 63 million tonnes. The stock of transport infrastructure is therefore growing with the consequence of increasing occupation and sealing of land, a contradiction to sustainable development. A total of about 230 million tonnes of materials in EU15 is stocked in transport vehicles. Due to lack of data, only passenger cars, commercial cars and merchant ships could be accounted for; therefore this number is a conservative estimate, probably lower than the real, unavailable figure. The annual input of about 13 million tonnes could be documented only for passenger cars. Therefore, a calculation of net stock increase by taking into account the material outputs as wastes (demolition of cars) and dissipative losses with a total of about 13 million tonnes does not make sense in the case of transport vehicles. Furthermore, transport vehicles carry an enormous ecological rucksack which has not been accounted for in this study.

Interpretation and policy applications

Material flow analysis of the transport sector reveals different aspects of environmental pressure. First, energy consumption renders the information about the magnitude of annual material throughputs causing environmental pressure both on the input and on the output side as described in Case Study I. These material flows were discussed in light of specific transport systems' material intensities, pointing out fields of priorities for structural changes in the transport sector. Second, the annual net stock increase of transport infrastructure gives an impression of the growth of the technosphere in this sector related to land occupation and land sealing along with a number of other environmental pressures. In addition, demolition waste arising from transport infrastructure

Material flow and stock accounts in the transport sector, European Union 1990 Table 9.7.

MODULES	INPUT	Mn t	STOCKS	Mn t	OUTPUTS	Mn t
Energy	**Fuels**	**2144**			**Fuels**	**2153**
	Fossil Energy Carriers	185			Emissions into air	833
	non-saleable production	90			Wastes	91
	O_2 for combustion	639			Waste water	1229
	Water	1229				
	Electricity: railway	**219**			**Electricity: railway**	**218**
	Fossil Energy Carriers	3			Emissions into air	11
	non-saleable production	5			Wastes	5
	O_2 for combustion	8			Waste water	196
	Water	202			Water evaporation	6
Vehicles			**Total**	**228**	**Total**	**13**
	Passenger cars	13	Passenger cars	145	Wastes	12
			Commercial cars	18	Dissipative losses	1
			Merchant ships	65		
Traffic ways	**Total**	**752**	**Total**	**138636**	**Total**	**63**
	Roads	734	Roads	137105	Demolition wastes	63
	Railway	17	Railway	1307	Dissipative losses	
	Navigable inland waterways		Navigable inland waterways	225		

demonstrates pressures on the environment by waste disposal, especially in view of the enormous quantities stocked in the technosphere. Third, counting the material stock and flows of transport vehicles results in the basis for estimating associated materials' movements and, as in the case of transport infrastructure, gives information about environmental pressures to come by future waste generation.

The global share of EU12 and EU15 in the different transport services may serve as a first indicator in the frame of the environmental space concept for pointing out reduction priorities in policy planning (Table 9.8). Compared with a global share of 6.2 and 6.9 % of the world population, the share of EU12 and EU15, respectively, in transport services is significantly higher in nearly all cases. Most obvious, however, is the proportionally high share in both road and air transport for passengers as well as for goods. Regarding material intensity, those two transport systems are obvious priorities for reduction. Besides the need for a total reduction of transport in a sustainable Europe, a shift from high material intensive to lower material intensive transport systems is an important option for European policy planning. The data presented here gives first indications for such strategic priority choices.

9.3. Measuring Progress Towards Sustainability in the Construction Sector (Case Study III)

Relevance of the sector

Although not dominant in any environmental debates of the past, the construction sector accounts for a significant share of the total material flows of our economies, and generates a comparably high share of their waste. Here, material flow analysis helps to identify one of the less obvious causes of environmental stress.

Definition of the sector

The construction sector itself is clearly defined by its activity according to the NACE ([87]) classification on the European level:

Code 45: Construction

Code 45.1	Site preparation
Code 45.2	Building of complete constructions or parts thereof; civil engineering
Code 45.3	Building installation
Code 45.4	Building completion
Code 45.5	Renting of construction or demolition equipment with operator

Naturally, there is a close connection of the construction sector to the energy sector (Case Study I) and to the transport sector

Table 9.8. **Global share of transport services by EU12 and EU15 in 1989**

	1989 World	1989 EU12	1989 EU15	EU12 % of World	EU15 % of World
Population in 1000s	**5295176**	**326646**	**363837**	**6.2**	**6.9**
Passenger-km (Bn.): Rail	2014	235	277	11,7	13.8
Passenger-km (Bn.): Air	809	341	367	42,1	45.4
Passenger-km (Bn.): Road	10783	3129	3462	29,0	32.1
Passenger-km (Bio.): Total	**13606**	**3705**	**4106**	**27.2**	**30.2**
Goods-transports: Tonnes-km (Bn.): Road	3106	833	905	26,8	29.1
Goods-transports: Tonnes-km (Bn.): Rail	5600	178	260	3.2	4.6
Goods-transports: Tonnes-km (Bn.): Inland waterways	1436	106	120	7.4	8.4
Goods-transports: Tonnes-km (Bn.): Pipelines	2789	64	73	2.3	2.6
Goods-transports: Tonnes-km (Bn.): Air	47	15	16	33.1	34.0
Goods-transports: Tonnes-km (Bn.): Total	**12978**	**1196**	**1374**	**9.2**	**10.6**

(Case Study II). However, material flows entering the construction sector for final consumption actually stem from a wide variety of other sectors of primary (e.g. forestry) and secondary (e.g. extraction of minerals, processing of construction materials) origin. However, materials extracted directly from the environment by construction activities are mainly excavated soil and water used for drainage purposes. Outputs to the environment from constructions are strongly determined by demolition waste. Another material flow closely related to construction activities in the long-term is the diversion of water by sealed surfaces, which has only recently attracted considerable attention in the context of unusually intensive floods in western Europe.

Sources of data

Data for construction materials is not available as such in official statistics. Using empirically derived information about materials used for construction ([88]), a wide range of these becomes apparent. In a first step, corresponding raw materials extraction from the environment could be quantified. ([89]) Using the same data source, the inland production of final construction materials (e.g. cement, bricks etc.) was obtained, which in turn may lead to an estimate of raw material inputs by using average coefficients. In general, however, it may be assumed that bulk materials for construction purposes at final consumption are provided by inland production rather than by imports. The magnitude of construction material trade by Germany has been examined in this study as an example. ([90])

A first and rough estimate of material flows used for construction may be further derived from physical data on the volume of buildings or from economic data on the value-added in the construction sector. By definition, the construction sector is likely to exhibit a high correlation between value-added and material inputs and outputs. This has been shown for Germany between 1960 and 1990 ([91]). On the European level, this method of estimation may be further validated by comparison with given numbers of demolition waste.

However, this monetary-based, comparative method cannot take into account different construction styles and systems. Searching for a more detailed picture of the materials used for construction in different European countries is, therefore, rather like assembling a puzzle. Quantitative information about the specific use of metals (steel and aluminium) in construction is partly available. ([92]) As described above, the domestic production of bulk mineral construction materials may be taken as a reference for real national consumption. This can be specified by estimating the material quantities used for the construction of transport routes by using physically based information (see Case Study II). However, it appears much more difficult to estimate the amount of materials used for the construction of residential and non-residential buildings to complete the picture for main infrastructure (buildings and transport ways). In this study, a first estimate of material flows for residential buildings was performed by taking into account the different availability of private houses vs. private apartments per capita in the individual Member States of the EU. From this, material flows were calculated by applying average material input coefficients as available for German representative building types. However, this still leaves the problem of estimating materials for non-residential buildings, which could only be overcome by assuming that the per capita availability in the EU15 is the same as in Germany. Also, the quantity of construction waste could only be estimated by assuming (and verifying for the German construction sector 1977 to 1990 ([93]) a constant ratio of waste generated to value-added.

Clearly, estimates conducted in this study cannot replace expert data acquisition and analysis in individual countries. Therefore, this report will primarily focus on data provided universally in international statistics (i.e. production of construction materials for final use etc.), verified by comparison with highly specified data on construction materials for Germany, elaborated in the Wuppertal Institute, department of material flows and structural change. Thus, the goal of this report is rather to present an exemplified overview of the different material flows to be considered in studying the environmental impact of the construction sector, and to point out fields of priority for sustainable material management in the context of policy.

Material flow analysis of different construction styles and systems

Material flow analysis related to the construction of individual types of buildings / infrastructure is still a matter of ongoing work in many European countries. For Germany, the topic has been implicitly taken up by the Federal Statistical Office in the context of

Table 9.9. **Material flows (in kg) per m³ of building type M 77**

Source: Harry Lehmann, Wuppertal Institute.

Construction materials	kg/m³ M 77
Concrete	146
Plaster and Composition floor	55
Bricks and various Stones	139
Ceramics	4.8
Other mineral products	1.1
Wood	5
Iron	8
PVC	0.7
Other	1.7
Total	360

Table 9.10. **Material flows (in kg) per m³ of different residential building types**

Type	Multiple dwelling-house (1)	Terrace house (2)	One-family house (3)	One-family house (4)
Period of construction	1969-1977	1969-1977	1969-1977	1960s and 1970s
Total materials (kg/m3)	360	390	480	497

Sources: (1) to (3): Harry Lehmann, Wuppertal Institute; (4): Baccini and Brunner 1991.

Table 9.11. **Material flows (in t) per m of transport ways**

Transport Routes	Material input tonnes per m
Roads	12
Inland waterways (canals)	e.g.: 26 (asphalt sealing) or 5.6 (embankment)
Railway	2

physical input-output tables. The Wuppertal Institute is working explicitly on material flow analyses of construction materials and construction styles and systems, both on the whole field of economy and on specific subjects. As an example, material inputs per m^3 are presented for a residential building type (M 77, i.e. a multiple dwelling house built in Western Germany in the period from 1969 to 1977) in Table 9.9.

To provide an overview of the range of specific material intensities (in kg materials used per m^3 building constructed) of buildings, material flows related to the construction of four typical residential building types in Western Germany are set out in Table 9.10.

Another dominant subject in the study of material flows for construction is transport routes (see Case Study II). Material flows for the construction of transport routes in western Germany have been examined. ([94]) So far, only very preliminary results can be presented in an aggregated manner (Table 9.11). The material content of roads refers to the west German average and does not even take into account moved earth which would add another 23 tonnes per metre of road. High material contents of canals result mainly from the huge amount of materials needed for sealing and paving.

Studies on material flows of individual construction types in general, provide necessary tools for material-based comparative evaluations of eco-efficiency. However, it is unlikely that the evaluation of material flows of the whole construction sector of an economy might be achieved from this bottom-up approach. Nonetheless, the aim of this study is to evaluate the possibilities of measuring progress towards sustainability in the entire building and construction sector. On the national or supra-national level this aim can only be achieved by a top-down approach, looking at the bulk material flows used for the construction of systems on a highly aggregated level.

Overall material efficiency of the construction sector and the relevance of logistics and maintenance

As the starting point of this study, the domestic availability of raw materials (minerals) potentially used for construction was quantified. Altogether, 16 individual, non-renewable raw materials were designated, accounting for a total of about 1.6 billion tonnes in the EU15 in 1988 ([95]) (Figure 9.8). Three base materials stand out: limestone and other calcium-containing stone; sand, silica and quartz; and gravel and crushed stone. From this, the final domestic consumption of construction materials could be obtained by quantifying imports and exports of raw materials, their relative share for construction purposes and the consumption of final construction materials by adjustment for import / export flows. This is, however, a rather unrealistic approach, and may only be carried out by individual studies in each country.

To proceed in a more practical way, the domestic production of processed materials for construction was quantified (Figure 9.9). Not surprisingly, these amount to about the same 1.6 to 1.7 billion tonnes for the EU15 as for raw materials, because the bulk materials sand, gravel and crushed stone, limestone and cement dominate the picture. It was assumed now that domestic production largely represents domestic consumption for those bulk materials. In the case of Germany (re-united Germany in 1991), this was examined in greater detail. In 1991, about 758 million tonnes of mineral raw materials were extracted within the country. In the same period, less than 10% of that, about 63 million tonnes of construction materials, were imported and about 46 million tonnes were exported, leaving a balance which is negligible in view of the masses extracted and processed within the country. This should, however, not lead to the conclusion that foreign trade of construction materials might be overlooked in regional material flow accounts. As construction materials represent primarily non-renewable materials used in large quantities, sooner or later their supply is likely to be depleted. This can be demonstrated on the German as well as on the European Union level. Concerning the role of Germany in the European Union in 1991, the country was a net exporter of construction materials (Figure 9.10). The majority of export and import trade was performed between adjacent countries primarily Belgium, the Netherlands and France. Recent trends, however, show that Germany itself is about to run short of bulk

Material flows in the construction sector of EU15 in 1988 Table 9.12.

	Domestic Production	**Deliveries for steel constructions**	**Consumption by building and construction**	
	1988 1000 t Minerals	**1988 1000 t Steel (basic and quality steel)**	**1988 1000 t Aluminium (primary and secondary)**	**1988 1000 t Total Construction Materials**
EUR 12	**1446511**	**5883**	**659**	**1453053**
EUR 15	**1665392**	**5883**	**671**	**1671947**
Belgique/Belgie	59243	113	17	**59373**
Danmark	15849	0	0	**15849**
Deutschland (West)	385485	587	191	**386264**
Ellas	17170	0	0	**17170**
Espana	126350	0	96	**126446**
France	267377	372	0	**267749**
Ireland	19275	0	0	**19275**
Italia	146001	3457	240	**149698**
Luxembourg	1493	0	28	**1521**
Nederland	50026	0	0	**50026**
Portugal	34555	0	0	**34555**
United Kingdom	323686	899	87	**324672**
Österreich	38856	0	12	**38868**
Sverige	12919	0	0	**12919**
Suomi/Finland	40732	0	0	**40732**
DDR	126374	0	0	**126374**
Deutschland	511859	587	191	**512638**
World	7170232	n.a.	n.a.	(7170232)

Table 9.13. **Material flows in the German construction sector 1990**

	Construction sector 1000 t	Construction sector % of total economy
Material Input		
Raw materials extraction	93189	8.54
Water consumption	20900	0.04
Oxygen (for combustion)	8011	1.09
Other materials	543458	1.01
Material Output		
Output of goods	364700	4.65
Emissions into air	10420	1.01
Waste water	19587	0.05
Wastes	107195	54.85

construction materials (especially gravel). Imports from Eastern European countries are increasing drastically, causing additional environmental pressure by long-range bulk transports. This clearly underlines the necessity for an overall reduction of material flows for construction purposes.

One possibility would be to increase the use of demolition waste, but despite recent efforts in many European countries to increase the recycling rates of demolition wastes, it is most unlikely that this will be sufficient to substitute significantly the quantities of primary materials used for construction at present consumption rates. Another possibility of increasing the eco-efficiency of construction in general would be to substitute non-renewable materials largely by renewable materials (like wood). However, even renewable materials cannot be considered as gratis regarding their ecological rucksacks, and again, it seems impossible that they could replace the bulk of construction materials consumed at present.

This leads to the conclusion that there is no alternative than to increase the overall eco-efficiency of constructions themselves. This goal may be achieved by a combination of strategies, including in general the choice of appropriate materials, the use of recycling materials, the possibilities of refurbishment instead of new construction and the establishment of engineering for dematerialised and service-oriented constructions.

In contrast to minerals, hardly any direct information is available on the European level regarding the use of other materials for construction purposes. Data available for the consumption of steel and aluminium point out that these materials, disregarding their ecological rucksacks, do not play a major role in the construction sector (Table 9.12). However, data presented in Table 9.12 represents only a part of the wide variety of materials used in construction. In particular, it does not account for regional differences in construction types, e.g. preferential use of wood in Scandinavia, less material-intensive houses built in the Netherlands compared to Germany, etc. Clearly, only very specific studies in the individual Member States of the European Union can improve our understanding of the use of construction materials. In any case, it may be assumed that data presented here represents the bulk of material flows used for construction purposes and may serve as a guideline for verification by individual country studies.

From this, only a very incomplete picture of the total relevance of the construction sector for material flows of the economy can be obtained. To give an impression of the role of the construction sector in total material flows of an economy, the German example is presented, resulting from a comprehensive data set on material flows obtained by physical input-output tables (Table 9.13). About 8.5% of the German raw materials extracted in 1990 was due to construction activities (i.e. soil excavation, which is an output as well in the form of waste). The majority of material inputs of about 543 million tonnes is represented by deliveries from other sectors of the economy, representing mainly processed construction materials as outlined in Table 9.12. The dominant contribution of the construction sector was, however, its contribution to waste generation representing more than half of all waste generated. The greater part of this waste (mainly soil excavation, demolition waste, road resurfacing waste) was actually disposed of in landfills. Therefore, increased recycling activities in this field would not only help to reduce the input of primary construction materials, but also to substantially decrease the pressure on waste disposal sites. Attempts to increase the recycling of construction wastes are presently underway in many European countries (e.g. Denmark intends to recycle about 60% of all construction waste by the year 2000).

Based on the data collected in this study and on estimates derived from the analysis of German data in the context of the economic

activities of the construction sector, a preliminary and incomplete picture of material flows and stocks in the European Union 1988/90 was obtained (Table 9.14). As described above, domestic production of construction materials accounts for nearly 1.7 billion tonnes, which together with an input of about 439 million tonnes by soil excavation, results in a total material input of about 2.1 billion tonnes (rucksacks of construction material inputs are not yet considered in this study). Soil excavation and demolition waste amount to about 579 million tonnes material output which results in a net stock increase of about 1.5 billion tonnes. This represents about 0.7% of the total stock in 1990, which consists of ca. 221 billion tonnes, more than half of which is stocked in roads. The technosphere of the European Union is thus growing at a rate of about 0.7% per year by material flows and, most probably, also by increasing related land use. This finding can be considered to be a basic contradiction of sustainability targets.

The choice of appropriate materials

In planning constructions, architects and others involved should be made aware of the material intensity of their projects by general material guidelines. By establishing comparative databases for individual construction materials, the choice of less material- and resource-intensive materials could be facilitated, in accordance with the specific material property or service desired. In this context, the following general guidelines should be considered:

- preference for the use of recycling materials in order to substitute for overall primary materials input and to reduce pressure on waste disposal;
- substitution of non-renewable by renewable materials, but only after consideration of their resource intensity and if the overall material intensity of the construction is reduced;
- substitution of high material-intensive materials (e.g. copper) by low material-intensive materials (e.g. plastics, but considering their individual ecotoxic potential etc.);

Material flow and stock accounts in the construction sector Table 9.14.

CONSTRUCTION SECTOR
EUROPEAN UNION (EU15) IN 1990

SECTOR	INPUT	Mn t	PRODUCTION	Mn t	STOCKS	Mn t	OUTPUTS	Mn t
Construction Materials	Raw Materials (Minerals)	1643	**Final Construction Materials**	**1672**			Wastes	
			* minerals	1665				
	Imports		* Steel	6			Exports	
			* Aluminium	1				
Constructions	***Total***	***2111***			***Constructions***	***221545***	***Total***	***579***
	Construktion Materials	**1672**			* **Buildings**	**82909**	**Demolition Wastes**	**140**
	* Minerals	1665			** residential	42851	* Buildings	77
	* Steel	6			** non-residential	40058	* Roads	63
	* Aluminium	1			* **Traffic Routes**	**138636**	* Others	
	Soil Excavation	**439**			** Roads	137105	**Soil Excavation**	**439**
	Energy				* Railway	1307	**Dissipative losses**	
	Water				* Inland waterways	255	**Emissions**	
					* Others		**Waste water**	
					Net Increase	**1532**		
					% of Stock	**0.69**		

- preference for refurbishing or adding on to existing constructions, thus saving material inputs and land use;
- preference for the lowest possible resource intensity for new constructions by an appropriate choice of materials, construction styles and intelligent land-use; such as multifunctionality (e.g. integrated solar energy generation, least possible sealed area, rain water use in domestic water consumption etc.).

Interpretation and policy applications

Despite significant lack of specific data, it has been shown in this study that construction activities in the European Union are associated with huge material flows creating environmental pressure both by material extraction and processing and by waste generated. As a result, construction activities are mainly responsible for increasing the technosphere by material stocks and corresponding land use, especially in the form of sealed surfaces. Possibilities have been pointed out to reduce the overall environmental impact of the construction sector. Recycling demolition waste or refurbishing old buildings are possibilities which are already being promoted in some European countries. However, in view of the enormous quantities of primary materials presently consumed for construction purposes in the European Union, it is very unlikely that this will be sufficient to significantly reduce the overall material input. In addition, the substitution of non-renewable by renewable materials cannot be considered as an alternative with respect to a quantitative substitution. In order to substantially increase the eco-efficiency of constructions, policy decisions will have to be based on wider considerations. As a general guideline, policy will have to encourage low resource-intensity constructions in terms of land use and material inputs, instead of the presently dominating practice of high material consumption and extended sealing of surfaces. This could include giving preference to the extension or re-construction of existing buildings instead of demolition and re-use of resulting waste materials. In addition, comparative and standardised information should be provided to support the choice of appropriate low resource-intensive construction materials and construction types. Altogether, these efforts could be combined in an intelligent low-resource planning of constructions, supported by policy with appropriate measures.

10. What Needs to be Done – Possible Contributions of the EEA

With respect to the potential of material-flow accounting, and with regard to the co-operation EEA's with Eurostat, the agency may support and contribute to the further development of a comprehensive, limited system of indicators for ecological sustainability.

10.1. Scientific Data and Databases

To proceed towards a regular and structured database for European material-flow accounting, the following conditions should be met:

- The physical basis of the European economy should be monitored by regular reports.
- Material Input flows should be quantified to indicate relevant environmental pressures.
- Documentation of the physical input should be complementary to the existing statistics on physical outputs (emissions etc.).
- The new reporting scheme should be largely based on existing statistics, thus minimising additional effort.
- Accounting of material flows should be related to the associated actors and activities.
- The method of accounting should be applicable at all levels (from the individual firm to the European level).
- The information derived must be adequate to support decision-making.

10.2. Establishment of a Structured Database

Largely based on existing statistics, a new comprehensive data compendium could be established to support the use of indicators as a means of working towards sustainability. This database would cover:

1. Domestic extraction and harvesting of raw materials. Physical quantities for the European Union and its Member States.
2. Physical data on imports and exports representing the content of primary materials. Foreign trade data should be provided according to the country of origin for imports and the country of destination for exports to quantify specific ecological rucksacks of imports (e.g. non-saleable production, erosion, energy consumption, materials consumed for transport, land area occupied for agricultural goods etc.).
3. Domestic output of materials to the environment in the form of waste, emissions into air and waste water. This would not only bridge the gap in traditional environmental statistics and policies, but would provide the most comprehensive waste data, complementing the European waste statistics.
4. Data on the ecological rucksacks of raw materials imported by the European Union. These material flows burdening the environment in foreign countries are part of the physical basis of the European Union and should be considered in decision-making towards sustainability.

Points 1, 2 and 3 summarise a consistent Material Flow Balance for the European Union, as it has already been performed for Austria ([96]) and Germany ([97]). The difference between physical inputs and outputs form the net accumulation of the physical stock of anthroposphere (e.g. buildings, infrastructures etc.).

The basic data as outlined above should be established in a time series in order to (i) study recent and current trends of individual material flows and (ii) permit informed prediction of future trends in the context of material flow-based indicators for sustainable development applying suitable economic models. Thus, the time series would be an important tool for priority setting in environmental policy.

The establishment of such databases would not need to start at zero. The Wuppertal Institute could provide detailed information and basic data on ecological rucksacks for the calculation of inter-regional material flow accounts.

10.3. Relation to Economic Activities

In general, material flows accounted for as

described above should be related to the corresponding economic activities. This is indispensable to providing information that can be put into practice. For pragmatic reasons, the existing European NACE classification should be used. In order to proceed to physical input-output tables, a stepwise approach can be followed. In the first step, the domestic extraction or harvesting of raw materials should be related to economic sectors, as well as the domestic output of materials to the environment in forms of waste, emissions into air and waste water. In the second step, the domestic production of goods has to be quantified in tonnes per economic sector, in order to arrive at the physical output of goods by sectors. In the third step, imports and exports have to be attributed to the NACE classification in order to obtain (i) the total domestic input of goods and (ii) the total domestic consumption of goods. In the fourth step, the interlinkages between economic sectors in terms of material flows have to be evaluated. The basis for this assessment is derived from the three steps performed before, i.e. by obtaining a vector of commodities to be distributed among the individual sectors of the economy. The quality of the physical input-output table will therefore depend mainly on:

(i) the number of individual commodities evaluated in physical terms;

(ii) the information available on the distribution of the commodities among the individual sectors of the economy.

The latter could be obtained from statistics about the goods received by individual sectors. Up to now, this information has been available in monetary terms. In the short run, this data can be used to calculate physical amounts. In the long run, primary statistical data will have to comprise physical records.

10.4. Establishment of a Computer-aided, Module-based Information System

In view of the huge amount of data collected and structured for material flow accounting, the use of a computer-based databank system is absolutely necessary. In general, such a databank system will have to provide the possibility to re-allocate material flow data to the main categories according to an agreed concept. In addition, it will have to include specific standardised processes, geographically defined, in order to account for the corresponding specific rucksacks (e.g. energy or transport). Thus, a number of individual modules will have to be introduced which provide general information required at any point of the account (e.g. material transport intensity per service unit, like tonne-km, for different modes of transport like air, water or road).

On the official national level, the German Federal Statistical Office, department of Environmental-Economic-Accounting (UGR), has developed a special material and energy flow information system (MEFIS). This system is also meant to bridge the gap between the “chaos” of basic data and the “order” of a structured material flow accounting framework. At present, no detailed information about MEFIS is obtainable.

11. Outlook

There can be no doubt that material flow accounting and the reduction factors linked to it are now on the international agenda. This has been recognised as a key element characterising economy-environment interlinkages, and as a tool for shaping proactive environmental policies. This holds true not only for the OECD, as confirmed by the environmental ministers' meeting in April 1998, but also – on initiative of the European Union – by the Rio+5 UNGASS Conference 1997.

In January, the UN DESA Expert group on Sustainable Consumption Indicators proposed to introduce the concept of material flow accounting ([98]) into the UN Sustainability Indicators used for the annual reporting to the CSD – a proposal picked up by the UN in the summer of 1998. ([99])

In March 1998, a first model of the EU15 economy based on embedded energy and material flow calculations was completed for the European Commission (DG XII), giving a direct insight into the interlinkage of material flows, economic growth and structural change. ([100]) Tools like this are also needed to properly assess the social and economic effects of sustainability policies before taking action.

Inside the EU, the Austrian Environmental Policy Plan ([101]) and recent Swedish legislation ([102]) refer to the concept. For the Netherlands and Germany, national material flow accounts have been published. ([103]) The German Ministery of the Environment's Draft National Environmental Strategy requests a material flow reduction by a factor of 2.5 by the year 2020 ([104]) – a goal well in line with the long-term perspective of a factor 10 dematerialisation. Other countries will probably follow suit, not least since the CSD recommendations to come will be an incentive to set up proper statistical reporting systems. In particular, since a number of EU Member States are participating in the pilot phase of the UN Sustainability Indicators programme (Austria, Belgium, Finland, France, Germany, UK), in which the new indices on sustainable consumption are to be introduced ([105]), the concept will be dealt with in one way or the other.

Harmonisation on the European level therefore seems to be of some urgency, and since Europe is holding the lead in this field a common initiative could make this very European concept a global standard.

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The Authors

Joachim H. Spangenberg studied Biology, Mathematics and Environmental Sciences in Cologne and Essen, FRG; Lecturer at the FHöV Cologne and the FH Dortmund;

Research fellow at the Institute for European Environmental Policy;

Senior research fellow at the Wuppertal Institute, Dept. of Material Flows and Structural Change, programme co-ordinator Sustainable Societies;

Board Member, INES (International Network of Engineers and Scientists for Global Responsibility);

Expert panel member for the development of sustainability indicators for the German Ministery of the Environment, EU DG XVI, the EUROSTAT EPI-project and the UNDPCSD CCPP project.

Current research issues include macroeconomic modelling of sustainable development, sustainability and labour, sustainable consumption, sustainability indicators.

Aldo Femia studied economics at Bacconi University in Milan and as a Ph.D. student in Ancona, Italy. He currently holds a post with the Italian Statistical Office; his ongoing research work includes Material Flow Accounting, Material Input analysis for Italy and the Input-Output analysis of material flows.

Friedrich Hinterberger received his diploma in economics from the University of Linz, Austria and his PhD from the University of Gießen, Germany. He is the officer in charge of the division for Material Flows and Structural Change of the Wuppertal Institute and a Member of the Administrative Board of the European Association for Ecological Economics. His academic work includes two books and a great number of articles in peer-reviewed books and journals. Main research interests include the economics of dematerialisation, socio-ecological economics and ecological economic policy.

Helmut Schütz studied Biology in Mainz, FRG. Diploma in Biology; Ph.D. in microbiology.

Research fellow at the Max-Planck-Institute for Chemistry in Mainz and the Fraunhofer Institute for Atmospheric Environmental Research in Garmisch-Partenkirchen;

Research fellow at the Wuppertal Institute, Department of Material Flows and Structural Change.

Friedrich Schmidt-Bleek studied Chemistry in Mainz/Germany. Founder/Director of the Appalachian Resources Project and the Environment Center, Univ. of Tennessee. Permanent Staff member of the Federal Environment Agency (UBA), Berlin. In the 1980s, head of OECD Chemicals Division, 1991 - 1997 Vice-President of the Wuppertal Institute. Since 1997: President of the Factor 10 Institute, Carnoules, France.

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